Table 12. (continued)

COUNTY	LANDSAT UNCORRECTED ESTIMATES HECTARES	LANDSAT UNCORRECTED ESTIMATES PROPORTION	LANDSAT CORRECTED ESTIMATES HECTARES	LANDSAT CORRECTED ESTIMATES PROPORTION
	(000)	(%)	(000)	(%)
SOUTHWEST DISTRICT				
CLARK	30.5	12.0	25.9	10.2
FINNEY	148.5	44.0	143.1	42.4
FORD	73.4	26.1	71.7	25.5
GRANT	39.0	26.5	9.8	6.6
GRAY	59.4	26.4	60.1	26.7
HAMILTON	138.5	53.9	114.3	44.5
HASKELL	30.9	20.6	30.9	20.6
HODGEMAN	114.5	51.4	96.7	43.4
KEARNEY	48.5	22.0	0.8	0.4
MEADE	20.7	8.2	14.4	5.7
MORTON	55.2	29.4	37.9	20.2
SEWARD	36.2	21.9	34.2	20.7
STANTON	63.8	36.4	47.3	27.0
STEVENS	61.6	32.6	28.3	15.0
TOTAL	920.7	30.0	715.4	23.3
SOUTH CENTRAL DISTRICT				
BARBER	88.5	29.8	89.4	30.1
COMANCHE	44.0	21.2	46.3	22.3
EDWARDS	44.4	27.9	46.6	29.3
HARPER	114.3	55.1	117.8	56.8
HARVEY	47.7	34.1	42.2	30.2
KINGMAN	118.8	53.1	124.8	55.8
KIOWA	43.4	23.2	45.6	24.4
PAWNEE	77.3	39.8	68.7	35.4
PRATT	76.8	40.6	80.5	42.6
RENO	123.3	37.9	108.3	33.3
SEDGWICK	116.6	45.1	117.3	45.4
STAFFORD	83.9	40.8	75.0	36.5
SUMNER	187.8	61.3	195.8	63.9
TOTAL	1166.8	40.2	1158.3	40.0
SOUTHEAST DISTRICT				
ALLEN	25.9	19.8	14.9	11.4
BOURBON	25.5	15.4	10.2	6.2
BUTLER	38.6	10.3	15.8	4.2
CHAUTAUQUA	23.5	14.1	0.0	0.0
CHEROKEE	34.3	22.5	22.1	14.5
COWLEY	53.3	18.1	43.0	14.6
CRAWFORD	24.9	16.1	10.8	7.0
ELK	27.9	16.7	0.0	0.0
GREENWOOD	59.8	20.1	0.0	0.0
LABETTE	34.5	20.3	20.4	12.0
MONTGOMERY	57.2	34.0	23.2	13.8
NEOSHO	24.2	15.9	10.4	6.8
WILSON	57.6	38.7	33.5	22.5
WOODSON	55.7	42.7	38.1	29.2
TOTAL	542.9	20.3	242.4	9.1
STATE TOTAL	5444.2	31.4	4612.9	26.6

Table 13. Comparison of USDA/SRS wheat harvested estimates and bias-corrected Landsat estimates of area and proportion of wheat in Kansas.

COUNTY	USDA/SRS HARVESTED HECTARES	USDA/SRS HARVESTED PROPORTION	LANDSAT CLASSIFICATION HECTARES	LANDSAT CLASSIFICATION PROPORTION	DIFFERENCE FROM SRS HECTARES	DIFFERENCE FROM SRS PROPORTION
	(000)	(%)	(000)	(%)	(000)	(%)
NORTHWEST DISTRICT						
CHEYENNE	61.0	22.9	82.6	31.0	21.7	8.1
DECATUR	48.6	20.9	31.4	13.5	-17.2	-7.4
GRAHAM	44.2	19.1	44.8	19.4	0.6	0.3
NORTON	42.3	18.5	50.3	22.1	8.0	3.5
RAWLINS	60.3	21.6	76.2	27.3	15.9	5.7
SHERIDAN	50.2	21.7	53.1	23.0	3.0	1.3
SHERMAN	73.1	26.7	25.8	9.4	-47.4	-17.3
THOMAS	90.4	32.6	22.6	8.2	-67.8	-24.5
TOTAL	470.1	23.3	386.8	19.2	-83.3	-4.1
NORTH CENTRAL DISTRICT						
CLAY	45.0	26.8	36.5	21.7	-8.5	-5.1
CLOUD	58.1	31.6	57.5	31.2	-0.6	-0.3
JEWELL	56.4	24.0	19.0	8.1	-37.4	-15.9
MITCHELL	71.2	38.4	86.7	46.7	15.6	8.4
OSBORNE	57.9	24.9	80.7	34.7	22.8	9.8
OTTAWA	66.3	35.4	53.5	28.6	-12.7	-6.8
PHILLIPS	35.8	15.4	17.9	7.7	-18.0	-7.7
REPUBLIC	47.1	25.3	52.6	28.2	5.5	3.0
ROOKS	53.6	23.3	72.2	31.4	18.6	8.1
SMITH	45.6	19.7	56.3	24.3	10.7	4.6
WASHINGTON	41.0	17.8	42.1	18.3	1.1	0.5
TOTAL	578.0	25.1	575.0	25.0	-3.0	-0.1
WEST CENTRAL DISTRICT						
GOVE	56.5	20.4	33.1	11.9	-23.4	-8.4
GREELEY	72.2	35.6	89.5	44.1	17.3	8.5
LANE	55.1	29.5	60.9	32.6	5.8	3.1
LOGAN	64.0	23.0	78.5	28.2	14.5	5.2
NESS	74.7	26.7	71.2	25.4	-3.5	-1.2
SCOTT	58.2	31.1	65.4	34.9	7.2	3.9
TREGO	49.8	21.3	60.3	25.8	10.5	4.5
WALLACE	35.0	14.8	61.3	26.0	26.3	11.1
WICHITA	56.1	29.9	58.4	31.1	2.4	1.3
TOTAL	521.6	25.2	578.6	28.0	57.0	2.8
CENTRAL DISTRICT						
BARTON	95.7	42.7	107.4	47.9	11.6	5.2
DICKINSON	72.3	32.6	91.5	41.3	19.3	8.7
ELLIS	54.8	23.5	108.2	46.4	53.5	22.9
ELLSWORTH	52.3	28.1	53.3	28.6	1.0	0.6
LINCOLN	53.8	28.6	54.5	28.9	0.6	0.3
MCPHERSON	99.6	43.0	103.9	44.8	4.3	1.9
MARION	65.1	26.2	68.5	27.6	3.4	1.4
RICE	78.5	42.0	95.2	51.0	16.8	9.0
RUSH	74.9	39.9	134.2	71.5	59.3	31.6
RUSSELL	56.7	24.8	56.8	24.8	0.1	0.0
SALINE	66.0	35.4	82.9	44.4	16.9	9.0
TOTAL	769.7	33.1	956.4	41.2	186.7	8.1

Table 13. (continued)

COUNTY	USDA/SRS HARVESTED HECTARES (000)	USDA/SRS HARVESTED PROPORTION (%)	LANDSAT CLASSIFICATION HECTARES (000)	LANDSAT CLASSIFICATION PROPORTION (%)	DIFFERENCE FROM SRS HECTARES (000)	DIFFERENCE FROM SRS PROPORTION (%)
SOUTHWEST DISTRICT						
CLARK	44.4	17.4	25.9	10.2	-18.5	-7.3
FINNEY	94.2	27.9	143.1	42.4	48.9	14.5
FORD	95.6	34.1	71.7	25.5	-23.9	-8.5
GRANT	36.2	24.6	9.8	6.6	-26.4	-18.0
GRAY	70.1	31.1	60.1	26.7	-10.0	-4.5
HAMILTON	62.7	24.4	114.3	44.5	51.6	20.1
HASKELL	46.1	30.7	30.9	20.6	-15.2	-10.1
HODGEMAN	55.5	24.9	96.7	43.4	41.2	18.5
KEARNEY	53.6	24.3	0.8	0.4	-52.9	-23.9
MEADE	62.9	24.9	14.4	5.7	-48.6	-19.2
MORTON	36.3	19.3	37.9	20.2	1.6	0.8
SEWARD	38.3	23.1	34.2	20.7	-4.1	-2.5
STANTON	49.9	28.5	47.3	27.0	-2.6	-1.5
STEVENS	38.1	20.2	28.3	15.0	-9.8	-5.2
TOTAL	783.9	25.6	715.4	23.3	-68.5	-2.3
SOUTH CENTRAL DISTRICT						
BARBER	69.1	23.3	89.4	30.1	20.3	6.8
COMANCHE	43.4	20.9	46.3	22.3	3.0	1.4
EDWARDS	53.1	33.4	46.6	29.3	-6.5	-4.1
HARPER	116.3	56.0	117.8	56.8	1.5	0.7
HARVEY	55.0	39.3	42.2	30.2	-12.8	-9.1
KINGMAN	97.0	43.3	124.8	55.8	27.9	12.4
KIOWA	51.3	27.5	45.6	24.4	-5.6	-3.0
PAWNEE	71.5	36.9	68.7	35.4	-2.8	-1.4
PRATT	82.6	43.7	80.5	42.6	-2.0	-1.1
RENO	146.4	45.0	108.3	33.3	-38.0	-11.7
SEDGWICK	105.3	40.7	117.3	45.4	12.0	4.6
STAFFORD	76.6	37.3	75.0	36.5	-1.6	-0.8
SUMNER	196.9	64.3	195.8	63.9	-1.1	-0.4
TOTAL	1164.5	40.2	1158.3	40.0	-6.2	-0.2
SOUTHEAST DISTRICT						
ALLEN	11.4	8.7	14.9	11.4	3.5	2.7
BOURBON	7.5	4.5	10.2	6.2	2.7	1.6
BUTLER	42.3	11.3	15.8	4.2	-26.6	-7.1
CHAUTAUQUA	8.9	5.3	0.0	0.0	-8.9	-5.3
CHEROKEE	18.9	12.5	22.1	14.5	3.1	2.1
COWLEY	64.3	21.8	43.0	14.6	-21.3	-7.2
CRAWFORD	10.9	7.0	10.8	7.0	-0.0	-0.0
ELK	8.9	5.3	0.0	0.0	-8.9	-5.3
GREENWOOD	6.9	2.3	0.0	0.0	-6.9	-2.3
LABETTE	20.8	12.3	20.4	12.0	-0.4	-0.2
MONTGOMERY	23.0	13.7	23.2	13.8	0.2	0.1
NEOSHO	14.1	9.3	10.4	6.8	-3.7	-2.4
WILSON	21.5	14.5	33.5	22.5	12.0	8.0
WOODSON	7.7	5.9	38.1	29.2	30.3	23.2
TOTAL	267.1	10.0	242.4	9.1	-24.7	0.9
STATE TOTAL	4554.9	26.2	4612.9	26.6	58.0	0.4

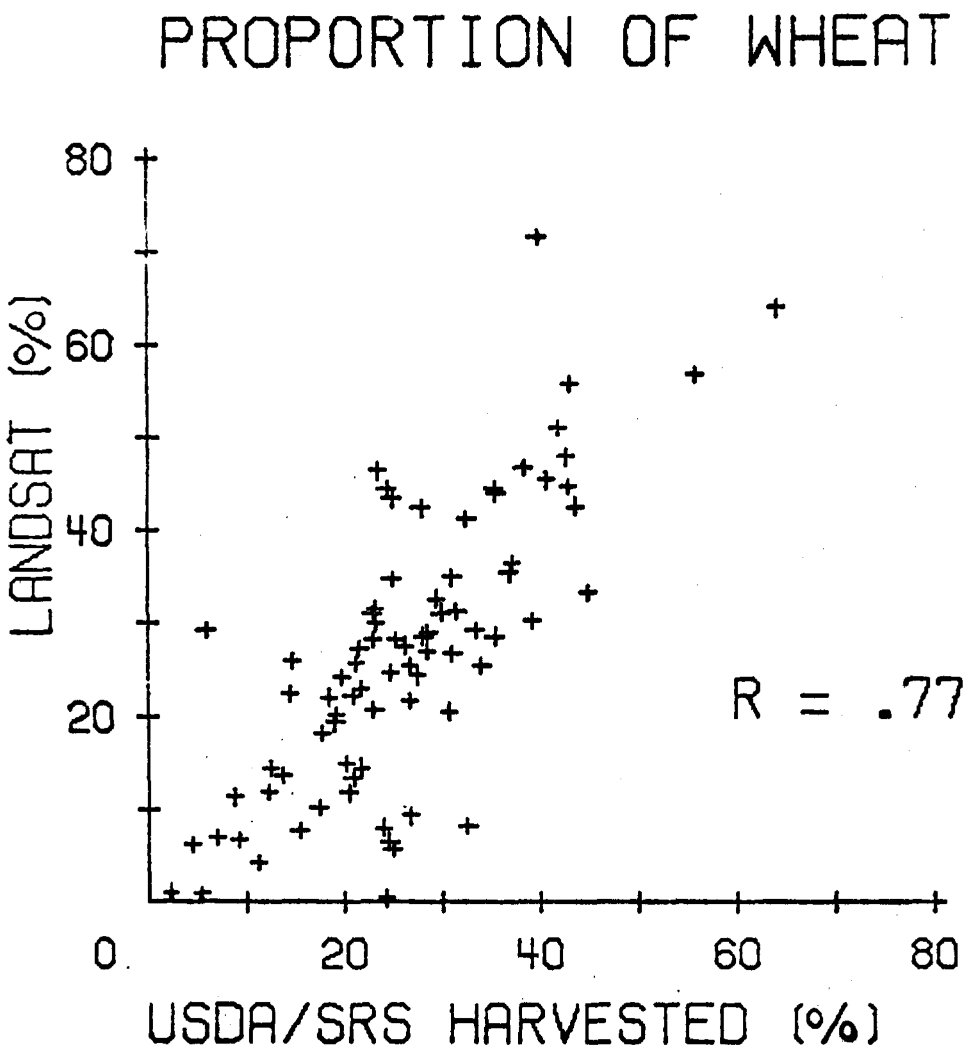

Figure 21. The correlation of Landsat and USDA/SRS estimates of the proportion of winter wheat in Kansas counties.

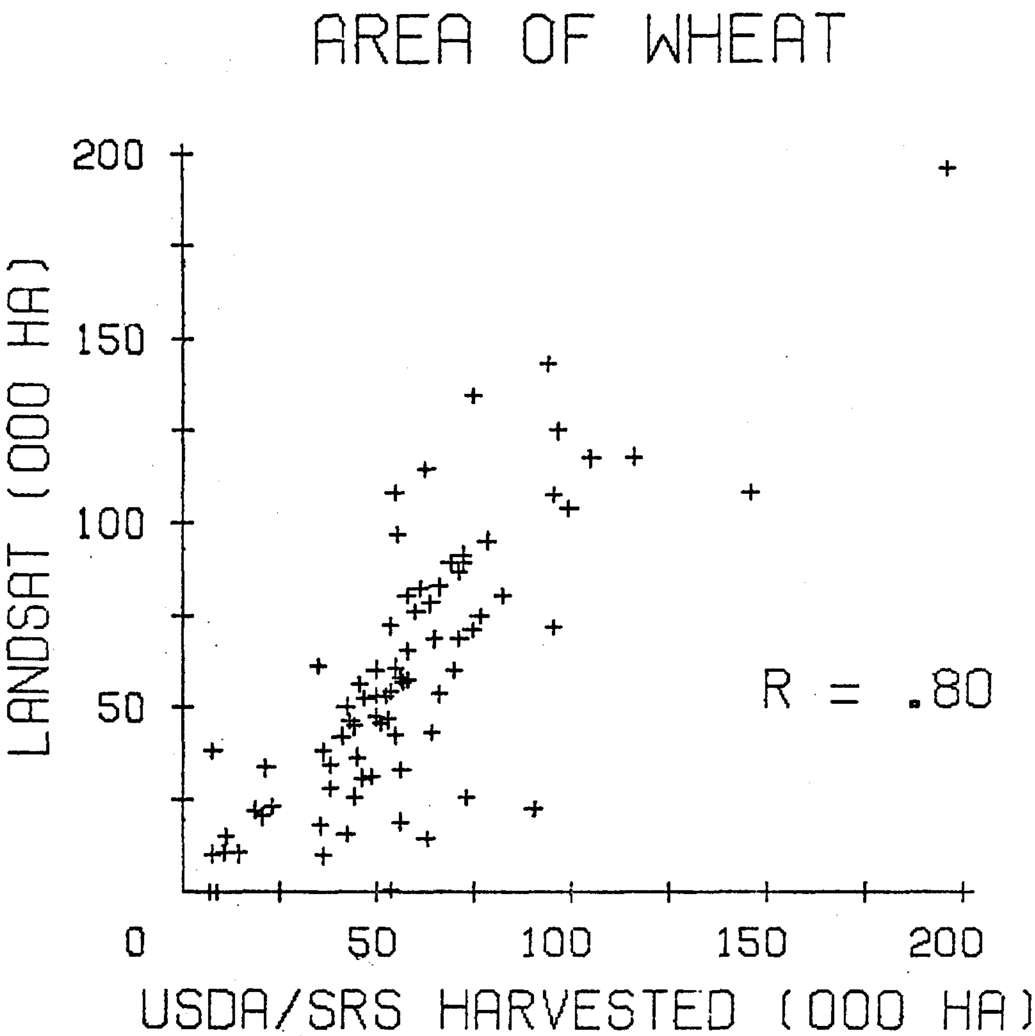

Figure 22. The correlation of Landsat and USDA/SRS estimates of the area of winter wheat in Kansas counties.

district, and county. A summary of the results at these three levels, including comparisons with the corresponding SRS estimates, is shown in Table 14. It should be noted that in comparing Landsat to SRS figures that the SRS figures are also estimates (and, thus subject to sampling error). The accuracy of the SRS estimates is greatest at the state level and least at the county level.

In tests of the accuracy of Landsat estimates at the state level, a large α was used to reduce the possibility of claiming that Landsat estimates were the same as SRS estimates when, in fact, they were not. T-tests were performed to determine if there was a significant difference between Landsat and SRS estimates. At the 25% significance level, there was no difference in the proportion or area of wheat.

At the crop reporting district level there was no significant difference in Landsat and SRS estimates of proportion or area of wheat except in the Central CRD. In the Central CRD, wheat was overestimated for every county in relation to the SRS estimates, creating a bias in the CRD estimate. However, all the county estimates were close to the SRS estimates except for two counties which accounted for most of the difference. The Central CRD is not the "worst" CRD when considering relative difference or average absolute difference from SRS as a measure of comparison between crop reporting districts (Table 15). On the whole,

Table 14. Summary of USDA/SRS and Landsat estimates of area and proportion of wheat in Kansas.

Region	Area USDA/SRS	Area Landsat	Area Difference	Proportion USDA/SRS	Proportion Landsat	Proportion Difference
	(000 Hectares)			(%)		
State	4555	4613	58	26.2	26.6	0.4
District						
Northwest	470	387	- 83	23.3	19.2	-4.1
North Central	578	575	- 3	25.1	25.0	-0.1
West Central	522	579	57	25.2	28.0	2.8
Central	770	956	187	33.1	41.2	8.1
Southwest	784	715	- 68	25.6	23.3	-2.3
South Central	1164	1158	- 6	40.2	40.0	-0.2
Southeast	267	242	- 25	10.0	9.1	-0.9
Counties (Median)	55.0	53.4	0.6	24.85	26.25	0.4

Table 15. Relative difference and average absolute difference between Landsat and SRS estimates for districts and state.

District	Landsat Estimate	Difference from SRS	Relative Difference	Average Absolute Difference
	(000 Ha)	(000 Ha)	(%)	(000 Ha)
Northwest	386.8	- 83.3	-21.5	22.7
North Central	575.0	- 3.0	- 0.5	13.8
West Central	578.6	57.0	9.9	12.3
Central	956.4	186.7	19.5	17.0
Southwest	715.4	- 68.5	- 9.6	25.4
South Central	1158.3	- 6.2	- 0.5	10.4
Southeast	242.4	- 24.7	-10.2	9.2
State	4612.9	58.0	1.3	

Landsat estimates were fairly close to SRS proportion and area estimates on a crop reporting district basis.

No statistical tests could be performed for differences from SRS estimates on a county-by-county basis because SRS does not calculate county variance estimates. Similarly, confidence limits cannot be placed around the SRS estimates. However, if the standard deviation of the SRS proportion estimates is assumed to be at least 10% at the county level, then 89% of the Landsat estimates were within a 90% confidence interval. For further comparison of Landsat and SRS county estimates, 49% of the counties were within $\pm 5\%$ (absolute difference) of SRS, 81% were within $\pm 10\%$, and 88% were within $\pm 15\%$.

5.3.3 Precision of Landsat Estimates

The second measure of the quality of an estimate is its precision which refers to the size of the deviations from its expected value obtained by repeated application of the sampling procedure. Using statistical theory, however, it is not necessary to repeatedly sample the population to determine the variance of an estimate.

The Landsat estimates are of a binomial nature since each point was classified as wheat or other. The variance of $\hat{\hat{p}}$ for a single county was calculated as:

$$v\left(\hat{\hat{p}}\right) = \frac{\hat{\hat{p}}\left(1-\hat{\hat{p}}\right)}{n-1}(1-f)$$

where $\hat{p}$ is the proportion estimate after correction for the bias, n is the number of pixels classified in the county, and $f=\frac{n}{N}$ where N is the total number of pixels in the county. The standard deviations for the districts and state were calculated considering the sample as stratified, but were approximately the same size as when calculated under the assumption of a systematic random sample throughout the CRD or state.

The standard deviations and coefficients of variation of the Landsat estimates are shown in Table 16. It can readily be seen that the standard deviations and the coefficients of variation (CV) are extremely small even at the county level. The CV of the SRS estimate of wheat acreage in the state of Kansas is 4%, compared to the CV of 0.06% for the Landsat estimate. The median CV of the Landsat county estimates is 0.60% which is smaller even than the 1.5% CV of the SRS national estimate of wheat acreage. Clearly the combined technologies of Landsat MSS data and computer-aided classification methods provides a means to make very precise crop area estimates.

Table 16. Estimates of the standard deviations and coefficients of variation of Landsat estimates of wheat in Kansas.

County	Area Estimate		Proportion Estimate		Coefficient of Variation
	Hectares	Standard Deviation	%	Standard Deviation	
	(000 Ha)	(Ha)		(%)	(%)
Northwest District					
Cheyenne	82.6	280.02	31.0	.1052	.33
Decatur	31.4	432.59	13.5	.1857	1.38
Graham	44.8	519.21	19.4	.2249	1.16
Norton	50.3	527.01	22.1	.2311	1.05
Rawlins	76.2	611.92	27.3	.2191	.80
Sheridan	53.1	235.82	23.0	.1019	.44
Sherman	25.8	184.11	9.4	.0674	.72
Thomas	22.6	375.80	8.2	.1356	1.65
Total	386.8	1191.33	19.2	.0590	.31
North Central District					
Clay	36.5	448.79	21.7	.2668	1.23
Cloud	57.5	566.41	31.2	.3074	.99
Jewell	19.0	359.92	8.1	.1532	1.89
Mitchell	86.7	567.23	46.7	.3058	.65
Osborne	80.7	604.48	34.7	.2598	.75
Ottawa	53.5	233.98	28.6	.1249	.44
Phillips	17.9	354.56	7.7	.1523	1.98
Republic	52.6	517.03	28.2	.2775	.98
Rooks	72.2	689.56	31.4	.2997	.95
Smith	56.3	561.17	24.3	.2425	1.00
Washington	42.1	621.13	18.3	.2691	1.47
Total	575.0	1721.33	25.0	.0747	.30
West Central District					
Gove	33.1	199.98	11.9	.0714	.60
Greeley	89.5	265.57	44.1	.1309	.30
Lane	60.9	289.98	32.6	.1555	.48
Logan	78.5	278.04	28.2	.1000	.35
Ness	71.2	271.56	25.4	.0969	.38
Scott	65.4	243.08	34.9	.1297	.37
Trego	60.3	249.10	25.8	.1067	.41
Wallace	61.3	249.47	26.0	.1057	.41
Wichita	58.4	236.34	31.1	.1260	.41
Total	578.6	763.55	28.0	.0369	.13

Table 16. (continued)

County	Area Estimate		Proportion Estimate		Coefficient of Variation
	Hectares	Standard Deviation	%	Standard Deviation	
	(000 Ha)	(Ha)		(%)	(%)
Central District					
Barton	107.4	269.37	47.9	.1202	.25
Dickinson	91.5	274.76	41.3	.1240	.30
Ellis	108.2	284.36	46.4	.1219	.26
Ellsworth	53.3	503.91	28.6	.2708	.95
Lincoln	54.5	522.31	28.9	.2777	.96
McPherson	103.9	283.67	44.8	.1223	.27
Marion	68.5	263.38	27.6	.1060	.38
Rice	95.2	562.69	51.0	.3012	.59
Rush	134.2	232.65	71.5	.1240	.17
Russell	56.8	537.75	24.8	.2351	.95
Saline	82.9	256.30	44.4	.1374	.31
Total	956.4	1277.74	41.2	.0550	.13
Southwest District					
Clark	25.9	182.06	10.2	.0714	.70
Finney	143.1	783.49	42.4	.2323	.55
Ford	71.7	269.07	25.5	.0959	.38
Grant	9.8	110.96	6.6	.0754	1.14
Gray	60.1	552.52	26.7	.2454	.92
Hamilton	114.3	308.61	44.5	.1200	.27
Haskell	30.9	412.53	20.6	.2750	1.33
Hodgeman	96.7	275.23	43.4	.1235	.28
Kearney	0.8	43.31	0.4	.0196	4.90
Meade	14.4	306.19	5.7	.1210	2.12
Morton	37.9	205.85	20.2	.1096	.54
Seward	34.2	433.69	20.7	.2619	1.27
Stanton	47.3	217.81	27.0	.1244	.46
Stevens	28.3	182.13	15.0	.0964	.64
Total	715.4	1336.91	23.3	.0436	.19

Table 16. (continued)

County	Area Estimate: Hectares	Area Estimate: Standard Deviation	Proportion Estimate: %	Proportion Estimate: Standard Deviation	Coefficient of Variation
	(000 Ha)	(Ha)		(%)	(%)
South Central District					
Barber	89.4	291.83	30.1	.0983	.33
Comanche	46.3	219.97	22.3	.1061	.48
Edwards	46.6	213.44	29.3	.1341	.46
Harper	117.8	265.85	56.8	.1281	.23
Harvey	42.2	209.98	30.2	.1501	.50
Kingman	124.8	278.11	55.8	.1243	.22
Kiowa	45.6	216.33	24.4	.1160	.48
Pawnee	68.7	244.64	35.4	.1261	.36
Pratt	80.5	252.87	42.6	.1339	.31
Reno	108.3	312.23	33.3	.0960	.29
Sedgwick	117.3	297.32	45.4	.1150	.25
Stafford	75.0	295.20	36.5	.1435	.39
Sumner	195.8	311.55	63.9	.1018	.16
Total	1158.3	954.06	40.0	.0329	.08
Southeast District					
Allen	14.9	138.02	11.4	.1055	.93
Bourbon	10.2	113.60	6.2	.0686	1.11
Butler	15.8	147.35	4.2	.0394	.94
Chautauqua	0.0	0.00	0.0	.0000	.00
Cherokee	22.1	162.31	14.5	.1067	.74
Cowley	43.0	224.81	14.6	.0764	.52
Crawford	10.8	122.77	7.0	.0792	1.13
Elk	0.0	0.00	0.0	.0000	.00
Greenwood	0.0	0.00	0.0	.0000	.00
Labette	20.4	156.22	12.0	.0922	.77
Montgomery	23.2	166.20	13.8	.0988	.72
Neosho	10.4	115.64	6.8	.0760	1.12
Wilson	33.5	187.84	22.5	.1263	.56
Woodson	38.1	194.02	29.2	.1486	.51
Total	242.4	532.05	9.1	.0199	.22
State Total	4612.9	3089.32	26.6	.0178	.07

5.4 Regression Estimation for Wheat in Areas without Landsat Coverage

Usable Landsat data was not available for the Northeast and East Central Crop Reporting Districts; thus those districts were not analyzed. Since estimates of area and proportion of wheat in the counties were required, a prediction equation was formulated using the 80 counties which had been classified with Landsat data. The Landsat wheat estimates were written as a function of historical wheat production in the two previous years and acres in the county. The prediction equation derived by this procedure was:

$$\hat{y} = 10274.97 + 0.66\, x_1 - 0.26\, x_2 - 0.02\, x_3$$

where x_1 is the acreage of wheat grown in a county in 1974, x_2 is the acreage of wheat grown in a county in 1973, x_3 is the number of acres in the county, and $\hat{y}$ is the "pseudo-Landsat" estimate in hectares. The R^2 value for the regression equation was 0.65.

Regression is good for prediction only when the x values corresponding to the estimate to be predicted fall within the range of the x values used in deriving the equation. If this held true for a given county, the estimate was made from the prediction equation. If this did not hold true, the USDA/SRS wheat estimate from the previous year was used. The estimates are presented in Table 17.

Table 17. Regression estimates of area and proportion of winter wheat in counties for which usable Landsat data was not available.

County	Proportion (%) SRS	Predicted	Diff.	Hectares (000) SRS	Predicted	Diff.
Northeast District						
*Atchison	10.3	7.0	-3.3	11.2	7.7	- 3.5
Brown	10.7	9.3	-1.4	16.0	14.0	- 2.0
*Doniphan	6.6	4.5	-2.1	6.5	4.4	- 2.1
Jackson	7.9	7.4	-0.5	13.4	12.6	- 0.8
Jefferson	7.2	8.7	1.5	9.9	11.9	2.0
*Leavenworth	6.6	4.3	-2.3	7.9	5.1	- 2.8
Marshall	17.2	14.4	-2.8	40.6	34.0	- 6.6
Nemaha	11.9	10.1	-1.8	21.8	18.6	- 3.2
Pottawatomie	7.9	6.2	-1.7	16.9	13.3	- 3.6
Riley	9.0	9.4	0.4	14.0	14.7	0.7
*Wyandotte	2.0	1.1	-0.9	0.8	0.4	- 0.4
Total	9.9	8.5	-1.4	159.0	136.7	-22.3
East Central District						
Anderson	8.5	7.2	-1.3	12.8	10.7	- 2.1
Chase	4.7	3.8	-0.9	9.5	7.7	- 1.8
Coffey	7.9	6.1	-1.8	13.4	10.4	- 3.0
*Douglas	9.7	7.2	-2.5	11.7	8.7	- 3.0
Franklin	8.6	8.4	-0.2	12.9	12.5	- 0.4
*Geary	11.3	10.2	-1.1	11.7	10.5	- 1.2
*Johnson	5.0	3.6	-1.4	6.1	4.4	- 1.7
Linn	5.3	4.7	-0.6	8.4	7.4	- 1.0
Lyon	8.6	5.2	-3.4	18.9	11.5	- 7.4
Miami	6.2	5.7	-0.5	9.5	8.8	- 0.7
Morris	14.0	13.2	-0.8	25.5	24.1	- 1.4
Osage	9.2	7.1	-2.1	17.1	13.1	- 4.0
Shawnee	10.6	11.7	1.1	14.9	16.3	1.4
Wabaunsee	6.1	5.0	-1.1	12.6	10.2	- 2.4
Total	8.2	6.9	-1.3	185.0	156.3	-28.7

*Historical estimates used.

The estimates obtained were tested for differences from SRS estimates of proportion and area of wheat harvested on a crop reporting district basis. There were significant differences from SRS in both area and proportion estimates in both crop reporting districts. Estimation from regression consistently underestimated wheat as did the historical estimates. Regression seems a reasonable alternative if Landsat estimation cannot be done for a given county, but a significant decrease in the accuracy of the estimates is likely to occur.

6.0 CORN AND SOYBEAN IDENTIFICATION AND AREA ESTIMATION IN INDIANA

The second state selected for analysis was Indiana; corn and soybeans, the two major grain crops in the state, were selected for study. This section includes the results of the Landsat data classifications and analyses. As for Kansas, the material presented includes a discussion of the factors affecting classification performance, comparisons of USDA/SRS and Landsat estimates of the area and proportions of the crops of interest, and evaluations of the accuracy and precision of the Landsat estimates.

6.1 Analysis of Factors Affecting Classification Accuracy

The effects of several factors likely to influence the accuracy of the Landsat area and proportion estimates were investigated. These included: Landsat acquisition date, aerial photography acquisition date, and local vs. nonlocal training and classification. There are, of course, many additional factors such as field size, number of crops and cover types present, uniformity of soils, and production practices, which may have also influenced the results, but which were beyond the scope of this investigation to pursue.

6.1.1 Effect of Landsat Acquisition Date

To study the effect of the date of Landsat coverage on the accuracy of the estimates, pairwise comparisons were made among three groups of dates (July, August, and September) without considering the effect of other factors. Different counties were in each group since all counties in Indiana were classified only once. The accuracy of an estimate was considered to be its closeness to the SRS estimate.

The estimates of the proportion and area of corn were significantly further from the SRS estimates ($\alpha \geq 0.02$) using September Landsat data than either July or August data. For soybean proportion and area estimation, the effect of Landsat acquisition date was not significant.

Estimates made from July and August Landsat data were not significantly different in accuracy for either corn or soybeans; thus, either date could be recommended. However, the August estimates of both corn and soybeans were closer in average difference to the SRS estimates than were the July estimates. Similar results were obtained in the CITARS experiments in which corn and soybeans in six Indiana and Illinois test sites were classified throughout the growing season [5].

6.1.2 Effect of Aerial Photography Acquisition Date

Three groups of dates (July, August, and September) also existed for the aerial photography acquisition dates. Although the groups are the same as for the study of Landsat acquisition date, the counties within each group were not always the same since photographic acquisition was not necessarily coordinated with Landsat data acquisition. Considering performance as a function of photography acquisition date only for corn estimation, both July and August estimates were significantly closer to the SRS estimates than September estimates were. For soybean estimation, August estimates were significantly closer to the SRS estimates than were the July estimates, while not significantly closer than September estimates.

Even though there was not a significant difference in the accuracy of July and August estimates for corn or of August and September estimates for soybeans, the August estimates were closer to the SRS estimates in both cases. The best time for aerial infrared photography acquisition appears to be August, coinciding with the optimal time period for the Landsat data acquisition. In some cases, multidate photography proved useful for identifying corn and soybeans when individual acquisition dates were not acquired at a good time for interpretation.

6.1.3 Effect of Local vs. Nonlocal Classification

The significance of the effect of local versus nonlocal classification depended upon the crop being estimated. Corn estimates were significantly better in nonlocal counties than in local recognition counties; an explanation of this unexpected result has not been identified. Soybean classification accuracy was not significantly affected by local versus nonlocal classification although local counties were closer to SRS estimates on the average.

6.2 Landsat Classification Results

The Indiana results include training field classification performances, estimates of the area and proportions of corn and soybeans for 43 counties in four districts, comparisons of the Landsat and USDA/SRS estimates, evaluation of the accuracy and precision of the estimates, and regression estimates for counties for which Landsat data were not analyzed.

6.2.1 Classification Accuracy

Classification accuracy was determined for Indiana by the training field performance matrices. No test fields were used in Indiana since it was felt that additional training data would be more valuable than having test fields; comparison of classification accuracies of training and test fields in Kansas showed them to be not significantly different. The training field classification performance for all local recognition counties is given in Table 18.

The training field classification performances are typically 75 to 85 percent. Although these accuracies are about 10 percent lower than obtained in Kansas, they would generally be considered adequate for making satisfactory area estimates provided a consistent bias was not present. As shall be shown in subsequent sections, the area and proportion estimates, particularly on a county basis, are not as accurate as might have been predicted from the training field classification performances. This is believed to be caused by a combination of two factors. First, the training performances are for "pure" pixels from the centers of fields; the area estimates, however, are made from samples including "mixed" or field boundary pixels. The proportion of pure pixels for Indiana fields which average only about 10 hectares in size is typically no more than 50 percent. Secondly, we encountered some difficulty in accurately identifying all fields as corn, soybeans, or other. Since positive identification of a field was required in order to use it for training, a significant number of fields representing several spectral classes was omitted from training. This would cause the training field classification performance to be biased upward.

6.2.2 Classification Bias Correction

Training field performance matrices were used to calculate

Table 18. Classification accuracy of training fields in Indiana.

County	Corn	Soybeans	Other	Overall
	Classification Accuracy (%)			
Benton	87.0	98.1	72.2	83.7
Lake	79.6	89.4	91.5	85.7
LaPorte	85.0	97.0	88.8	89.1
Newton	86.2	97.1	70.0	84.1
Pulaski	92.3	98.2	85.8	91.6
Starke	92.3	98.2	85.8	91.6
White	90.9	89.8	78.7	87.5
Fountain	88.6	91.9	79.8	86.1
Montgomery	84.6	89.8	81.2	85.6
Owen	87.2	64.0	94.2	84.1
Parke	88.6	91.9	79.8	86.1
Tippecanoe	98.3	90.9	86.9	92.5
Vigo	61.8	60.4	89.6	75.9
Warren	95.3	94.4	92.2	93.9
Decatur	79.4	98.1	79.1	85.3
Grant	91.8	98.5	72.7	89.2
Hamilton	71.6	98.0	76.6	81.1
Hancock	85.1	99.1	84.8	90.4
Howard	71.6	98.0	76.6	81.1
Johnson	90.3	93.7	94.8	92.5
Madison	88.4	97.6	73.3	88.8
Shelby	90.3	93.7	94.8	92.5
Tipton	71.6	98.0	76.6	81.1
Fayette	90.5	90.9	85.1	88.5
Jay	73.5	88.5	81.5	83.6
Randolph	84.4	95.5	75.9	87.8
Wayne	88.1	94.7	82.3	88.3

the bias in the absence of test fields; the Kansas analysis had demonstrated this was feasible. Also following the results from the Kansas analysis, error matrices were extended to nonlocal recognition counties.

All crop estimates were corrected for the bias because this operation brought them closer to SRS estimates on the average. For soybeans, there was no significant difference at any reasonable α level in the accuracy of corrected and uncorrected estimates. For corn estimates, however, corrected estimates were closer to SRS at the 20% significance level.

6.3 Corn and Soybean Area and Proportion Estimates

Tables 19 and 20 present the results of the Landsat classifications on a county-by-county basis. Estimates for both proportion and area of corn and soybeans are given as the uncorrected and bias-corrected values. The values used in the statistical analysis were always the bias-corrected estimates.

6.3.1 Correlation of Landsat and USDA/SRS Estimates of Area and Proportion of Corn and Soybeans

Plots of the Landsat vs. SRS county estimates of corn and soybean area and proportions, along with correlation estimates, are shown in Figures 23-26. The two estimates are not as highly correlated as the Kansas estimates; three counties, however, accounted for much of the lack of correlation of the corn estimates. The Landsat estimates for corn are

Table 19. Uncorrected and bias-corrected Landsat estimates of hectares and proportions of corn in Indiana.

County	Uncorrected Hectares	Uncorrected Proportion	Bias-Corrected Hectares	Bias-Corrected Proportion
	(000)	(%)	(000)	(%)
Northwest District				
Benton	53.5	50.5	53.6	50.6
Jasper	36.8	25.3	92.0	63.3
Lake	56.1	42.1	62.7	47.1
LaPorte	60.8	38.6	64.7	41.1
Newton	63.2	59.3	63.0	59.2
Porter	47.2	42.9	53.1	48.2
Pulaski	54.0	48.1	54.1	48.2
Starke	38.8	48.2	38.1	47.3
White	66.6	51.7	63.4	49.2
Total	477.0	44.2	544.7	50.4
West Central District				
Clay	17.1	18.1	18.0	19.1
Fountain	45.9	44.6	42.2	41.0
Montgomery	60.8	46.3	62.2	47.4
Owen	23.2	23.3	19.2	19.2
Parke	50.1	42.9	44.4	38.0
Putnam	39.8	31.5	36.2	28.6
Tippecanoe	56.7	43.7	53.0	40.8
Vermillion	34.4	50.5	33.5	49.2
Vigo	20.2	18.8	21.7	20.2
Warren	38.0	39.9	35.9	37.6
Total	386.2	36.0	366.3	34.2

Table 19. (continued)

County	Uncorrected Hectares	Uncorrected Proportion	Bias-Corrected Hectares	Bias-Corrected Proportion
	(000)	(%)	(000)	(%)
Central District				
Bartholomew	20.3	19.5	3.4	3.3
Boone	19.6	17.7	5.6	5.1
Clinton	17.1	16.2	2.4	2.3
Decatur	38.5	40.2	37.3	38.9
Grant	42.3	38.8	31.0	28.4
Hamilton	35.8	34.5	38.0	36.6
Hancock	29.6	37.5	30.6	38.7
Hendricks	41.6	38.5	48.2	44.6
Howard	31.8	41.9	39.5	52.0
Johnson	32.1	39.3	32.6	39.9
Madison	51.3	43.7	46.7	39.8
Marion	28.5	27.4	15.1	14.5
Morgan	19.3	18.3	15.3	14.5
Rush	38.6	36.4	38.8	36.6
Shelby	51.6	48.7	54.0	51.0
Tipton	26.8	39.7	33.7	49.9
Total	524.8	33.2	472.2	29.9
East Central District				
Blackford	13.2	30.4	15.2	35.2
Delaware	41.8	40.5	43.9	42.6
Fayette	15.3	27.5	13.3	23.8
Henry	25.9	25.0	23.8	23.0
Jay	27.3	27.3	30.9	30.9
Randolph	46.8	39.5	49.0	41.4
Union	13.9	31.9	12.4	28.4
Wayne	26.5	25.3	23.0	21.9
Total	210.7	31.3	211.5	31.4
State	1598.7	36.3	1594.7	36.2

Table 20. Uncorrected and bias-corrected Landsat estimates of hectares and proportions of soybeans in Indiana.

County	Uncorrected Hectares	Uncorrected Proportion	Bias-Corrected Hectares	Bias-Corrected Proportion
	(000)	(%)	(000)	(%)
Northwest District				
Benton	22.6	21.3	20.3	19.2
Jasper	22.8	15.7	22.4	15.4
Lake	24.0	18.0	22.1	16.6
LaPorte	32.9	20.9	32.9	20.9
Newton	13.5	12.7	12.4	11.6
Porter	22.6	20.5	21.4	19.4
Pulaski	32.3	28.8	32.6	29.1
Starke	18.3	22.7	18.5	22.9
White	27.4	21.3	26.4	20.5
Total	216.4	20.0	209.0	19.3
West Central District				
Clay	19.4	20.6	26.0	27.6
Fountain	12.7	12.3	11.6	11.3
Montgomery	23.1	17.6	24.4	18.6
Owen	12.5	12.5	15.6	15.6
Parke	11.1	9.5	9.3	8.0
Putnam	16.9	13.4	21.1	16.7
Tippecanoe	23.9	18.4	23.4	18.0
Vermillion	8.0	11.8	7.5	11.0
Vigo	22.2	20.6	29.6	27.5
Warren	11.5	12.1	12.2	12.8
Total	161.3	15.0	180.7	16.9

Table 20. (continued)

County	Uncorrected Hectares	Uncorrected Proportion	Bias-Corrected Hectares	Bias-Corrected Proportion
	(000)	(%)	(000)	(%)
Central District				
Bartholomew	15.7	15.1	15.7	15.1
Boone	38.4	34.7	38.6	34.9
Clinton	37.0	35.1	37.2	35.3
Decatur	15.5	16.2	15.6	16.3
Grant	22.8	20.9	21.1	19.3
Hamilton	29.7	28.6	29.3	28.2
Hancock	23.1	29.2	21.8	27.6
Hendricks	30.7	28.4	30.1	27.9
Howard	22.5	29.6	22.0	29.0
Johnson	33.3	40.8	34.9	42.8
Madison	30.4	25.9	28.1	23.9
Marion	12.3	11.8	11.7	11.2
Morgan	9.8	9.3	11.3	10.7
Rush	29.8	28.1	30.9	29.2
Shelby	32.2	30.4	33.4	31.5
Tipton	23.5	34.8	23.3	34.4
Total	406.7	25.7	405.0	25.6
East Central District				
Blackford	12.7	29.3	11.6	26.7
Delaware	37.3	36.2	33.0	32.0
Fayette	12.4	22.2	12.3	22.1
Henry	28.6	27.6	24.3	23.4
Jay	34.6	34.6	33.3	33.3
Randolph	43.7	36.9	38.8	32.8
Union	6.7	15.3	6.2	14.3
Wayne	16.5	15.7	10.0	9.5
Total	192.5	28.6	169.5	25.2
State	976.9	22.2	964.2	21.9

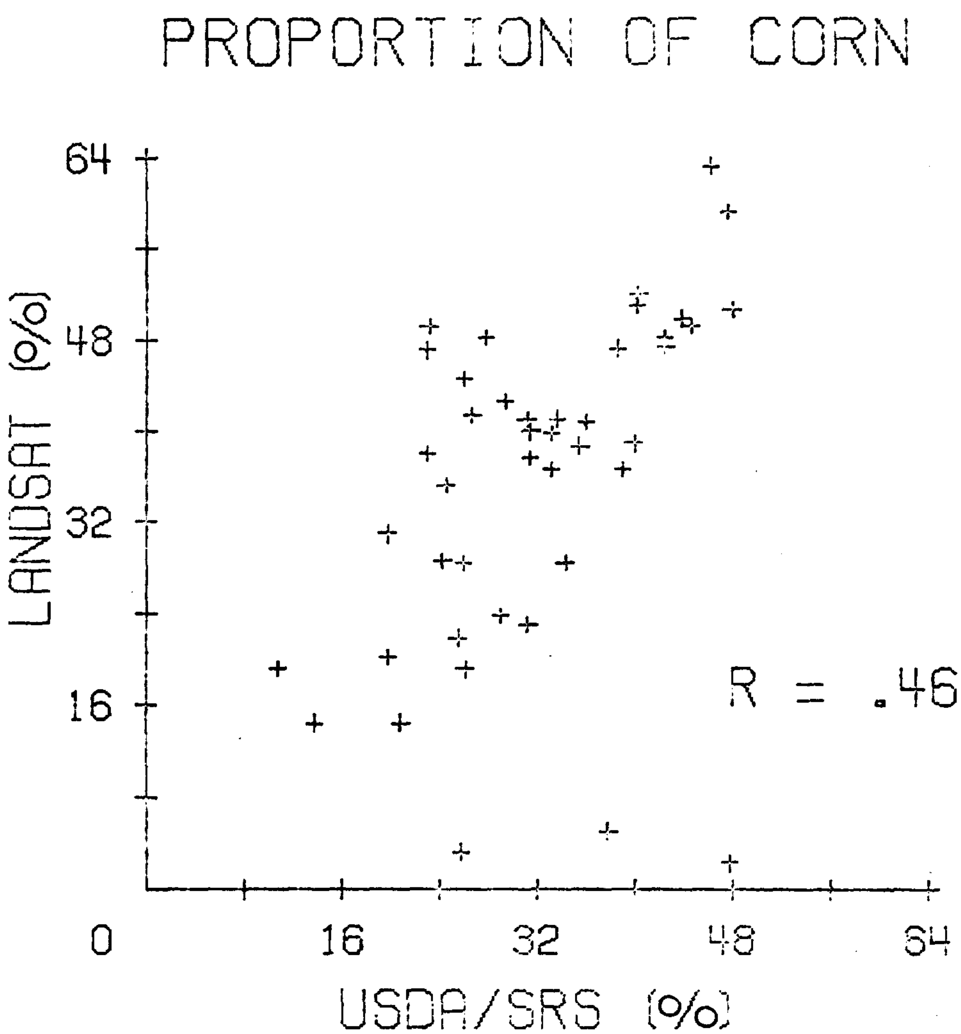

Figure 23. The correlation of Landsat and USDA/SRS estimates of the proportion of corn in Indiana counties.

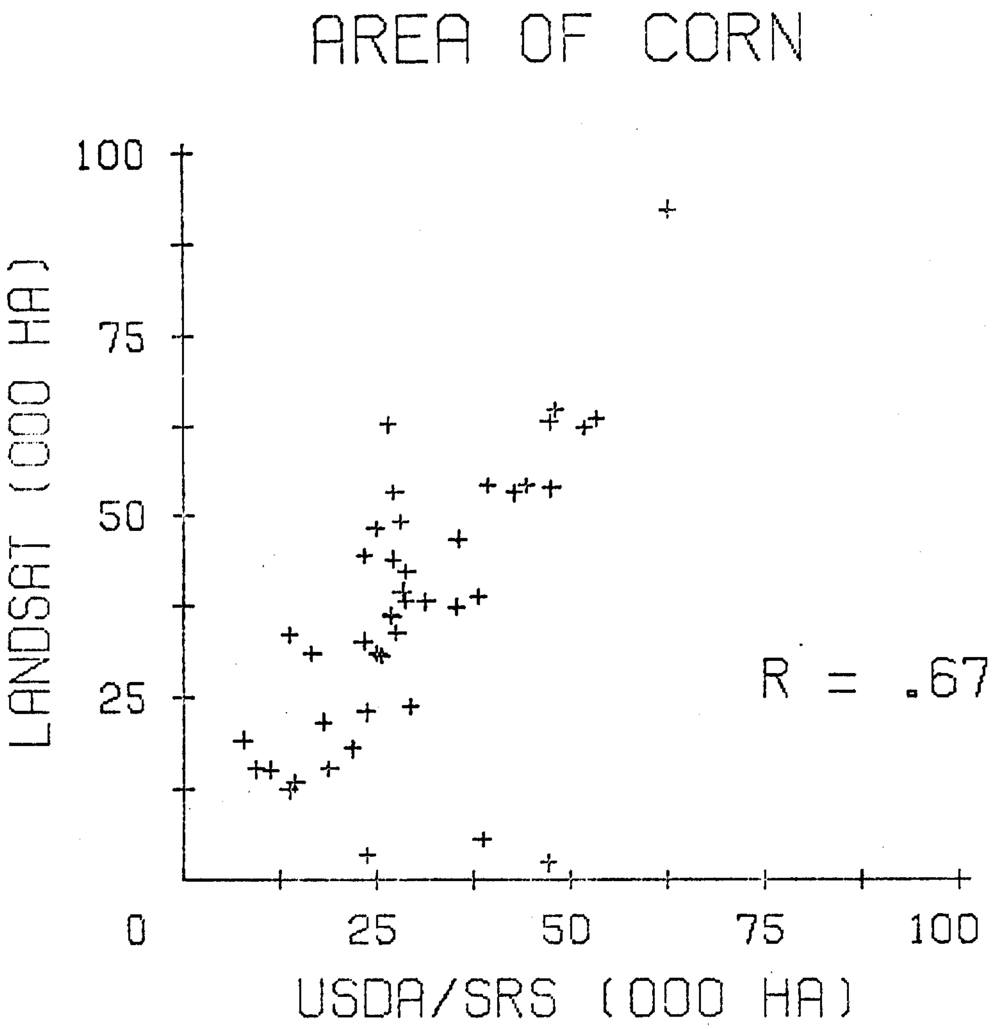

Figure 24. The correlation of Landsat and USDA/SRS estimates of the area of corn in Indiana counties.

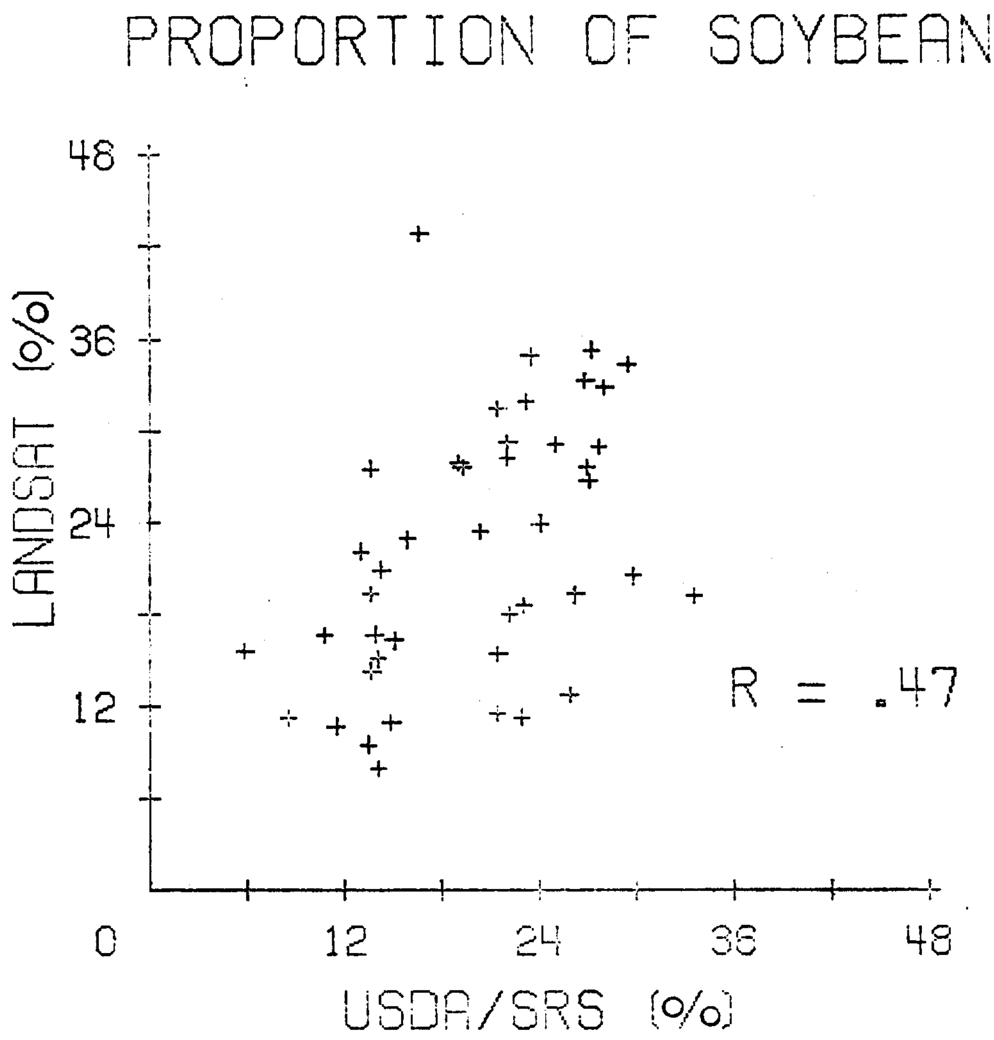

Figure 25. The correlation of Landsat and USDA/SRS estimates of the proportion of soybeans in Indiana counties.

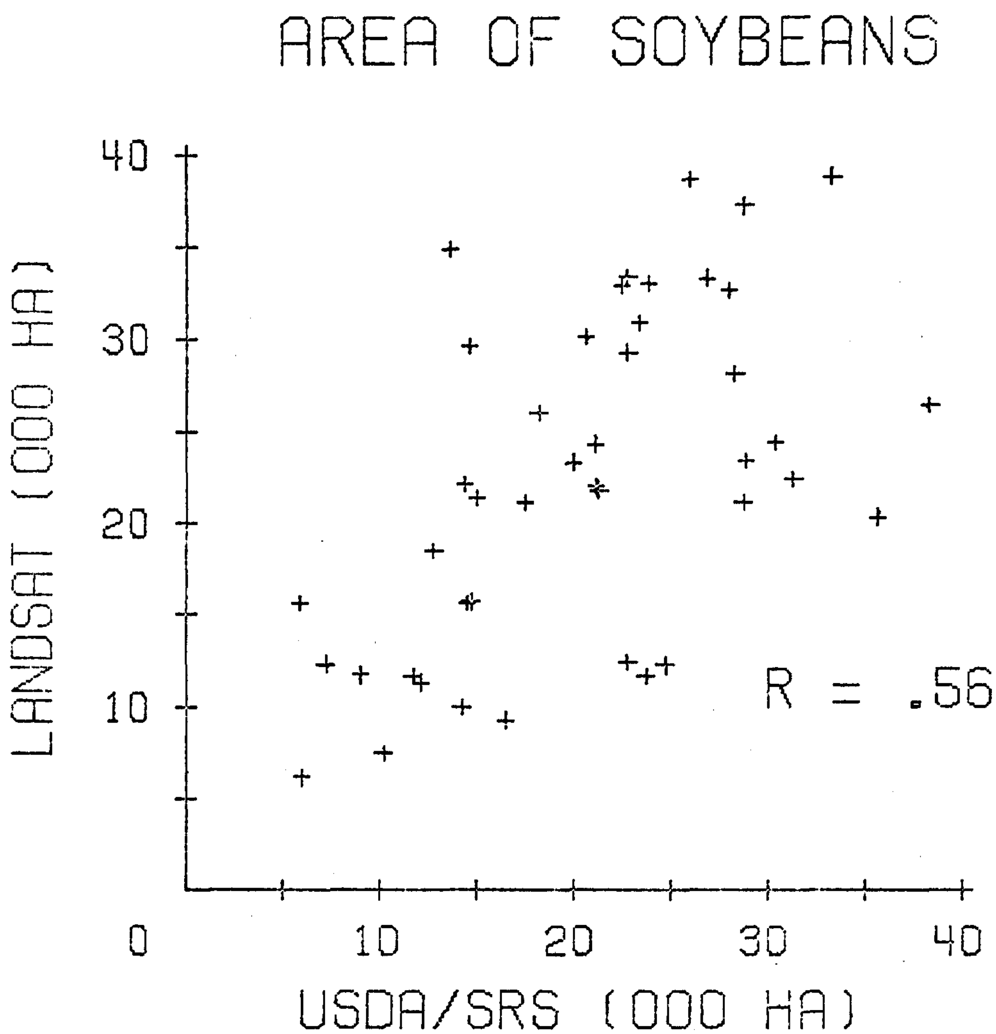

Figure 26. The correlation of Landsat and USDA/SRS estimates of the area of soybeans in Indiana counties.

consistently greater than the SRS estimates. On the other hand, the Landsat soybean estimates do not appear biased, but are clearly more variable than either the corn or Kansas wheat estimates.

More quantitative comparisons of the Landsat and SRS estimates at the county, as well as the district and "state" levels, are shown in Tables 21 and 22.

6.3.2 Accuracy of Estimates

Only four of Indiana's crop reporting districts were estimated using Landsat classification methods. These four districts together make up a "pseudo" state estimate which was tested against an SRS "pseudo" state estimate. The Landsat corn proportion and area estimates were significantly different from the SRS estimates. The soybean estimates were closer to SRS estimates, but the differences became significant at the 20% level for both proportion and area estimates. Assuming that the SRS estimates were unbiased in these crop reporting districts, the estimates derived from the Landsat classification were not as accurate as the SRS estimates.

Tests were also performed for differences from SRS estimates on a crop reporting district basis. In the Northwest and West Central Districts, corn estimates were significantly different from SRS, while soybean estimates were not significantly different. In the Central District, the reverse was found: corn estimates were not significantly different from

Table 21. Comparison of USDA/SRS corn estimates and bias-corrected Landsat estimates of area and proportion of corn in Indiana.

	Proportion (%)			Hectares (000)		
County	SRS	Landsat	Diff.	SRS	Landsat	Diff.
Northwest District						
Benton	44.9	50.6	5.7	47.6	53.6	6.0
Jasper	43.2	63.3	20.1	62.8	92.0	29.2
Lake	20.0	47.1	27.1	26.6	62.7	36.1
LaPorte	30.6	41.1	10.5	48.1	64.7	16.6
Newton	44.6	59.2	14.6	47.4	63.0	15.6
Porter	24.8	48.2	23.4	27.3	53.1	25.8
Pulaski	39.4	48.2	8.8	44.2	54.1	9.8
Starke	35.6	47.3	11.7	28.7	38.1	9.4
White	41.6	49.2	7.6	53.5	63.4	9.8
Total	35.8	50.4	14.6	386.2	544.7	158.5
West Central District						
Clay	23.1	19.1	- 4.0	21.8	18.0	- 3.8
Fountain	28.1	41.0	12.9	29.0	42.2	13.2
Montgomery	39.5	47.4	7.9	51.8	62.2	10.4
Owen	7.8	19.2	11.4	7.7	19.2	11.5
Parke	20.0	38.0	18.0	23.4	44.4	21.0
Putnam	21.3	28.6	7.3	26.9	36.2	9.3
Tippecanoe	33.0	40.8	7.8	42.8	53.0	10.2
Vermillion	20.1	49.2	29.1	13.7	33.5	19.8
Vigo	16.8	20.2	3.4	18.1	21.7	3.6
Warren	28.4	37.6	9.2	27.0	35.9	8.8
Total	24.4	34.2	9.8	262.2	366.3	104.1

Table 21. (continued)

County	Proportion (%) SRS	Landsat	Diff.	Hectares (000) SRS	Landsat	Diff.
Central District						
Bartholomew	22.8	3.3	-19.5	23.7	3.4	-20.3
Boone	34.9	5.1	-29.8	38.6	5.6	-33.0
Clinton	44.8	2.3	-42.5	47.2	2.4	-44.8
Decatur	36.9	38.9	2.0	35.3	37.3	1.9
Grant	23.0	28.4	5.4	25.1	31.0	5.8
Hamilton	30.2	36.6	6.4	31.4	38.0	6.6
Hancock	32.5	38.7	6.2	25.7	30.6	4.9
Hendricks	23.0	44.6	21.6	24.9	48.2	23.3
Howard	37.3	52.0	14.7	28.3	39.5	11.1
Johnson	28.5	39.9	11.4	23.3	32.6	9.3
Madison	30.2	39.8	9.6	35.5	46.7	11.2
Marion	10.8	14.5	3.7	11.3	15.1	3.8
Morgan	17.9	14.5	- 3.4	18.9	15.3	- 3.6
Rush	36.0	36.6	0.6	38.1	38.8	0.7
Shelby	37.2	51.0	13.8	39.4	54.0	14.7
Tipton	40.8	49.9	9.1	27.6	33.7	6.1
Total	30.0	29.9	- 0.1	474.3	472.2	- 2.1
East Central District						
Blackford	21.5	35.2	13.7	9.3	15.2	5.9
Delaware	26.4	42.6	16.2	27.2	43.9	16.7
Fayette	26.0	23.8	- 2.2	14.5	13.3	- 1.2
Henry	28.3	23.0	- 5.3	29.3	23.8	- 5.5
Jay	16.7	30.9	14.2	16.7	30.9	14.2
Randolph	23.7	41.4	17.7	28.1	49.0	21.0
Union	31.2	28.4	- 2.9	13.6	12.4	- 1.2
Wayne	22.5	21.9	- 0.6	23.6	23.0	- 0.6
Total	24.1	31.4	7.3	162.3	211.5	49.2
State	29.2	36.2	7.0	1285.0	1594.7	309.7

Table 22. Comparison of USDA/SRS soybean estimates and bias-corrected Landsat estimates of area and proportion of soybeans in Indiana.

	Proportion (%)			Hectares (000)		
County	SRS	Landsat	Diff.	SRS	Landsat	Diff.
Northwest District						
Benton	33.6	19.2	-14.4	35.6	20.3	-15.2
Jasper	21.5	15.4	- 6.1	31.3	22.4	- 8.9
Lake	10.8	16.6	5.8	14.4	22.1	7.7
LaPorte	14.3	20.9	6.6	22.5	32.9	10.4
Newton	21.4	11.6	- 9.8	22.8	12.4	-10.4
Porter	13.6	19.4	5.8	15.0	21.4	6.3
Pulaski	25.0	29.1	4.1	28.0	32.6	4.6
Starke	15.9	22.9	7.0	12.8	18.5	5.7
White	29.8	20.5	- 9.3	38.3	26.4	-11.9
Total	20.4	19.3	- 1.1	220.7	209.0	-11.7
West Central District						
Clay	19.5	27.6	8.1	18.4	26.0	7.6
Fountain	23.0	11.3	-11.7	23.7	11.6	-12.1
Montgomery	23.1	18.6	- 4.5	30.4	24.4	- 5.9
Owen	5.9	15.6	9.7	5.9	15.6	9.7
Parke	14.1	8.0	- 6.1	16.5	9.3	- 7.1
Putnam	13.9	16.7	2.8	17.5	21.1	3.6
Tippecanoe	22.2	18.0	- 4.2	28.9	23.4	- 5.5
Vermillion	14.9	11.0	- 3.9	10.2	7.5	- 2.7
Vigo	13.6	27.5	13.9	14.6	29.6	15.0
Warren	25.9	12.8	-13.1	24.7	12.2	-12.5
Total	17.8	16.9	- 0.9	190.8	180.7	-10.1

Table 22. (continued)

County	Proportion (%) SRS	Landsat	Diff.	Hectares (000) SRS	Landsat	Diff.
Central District						
Bartholomew	14.1	15.1	1.0	14.7	15.7	1.1
Boone	23.5	34.9	11.4	26.0	38.6	12.6
Clinton	27.3	35.3	8.0	28.8	37.2	8.4
Decatur	15.1	16.3	1.2	14.4	15.6	1.2
Grant	26.3	19.3	- 7.0	28.7	21.1	- 7.7
Hamilton	22.0	28.2	6.2	22.8	29.3	6.5
Hancock	27.0	27.6	0.6	21.3	21.8	0.5
Hendricks	19.1	27.9	8.8	20.6	30.1	9.5
Howard	27.8	29.0	1.2	21.1	22.0	0.9
Johnson	16.7	42.8	26.1	13.6	34.9	21.3
Madison	24.1	23.9	- 0.2	28.3	28.1	- 0.3
Marion	8.6	11.2	2.6	9.0	11.7	2.7
Morgan	11.6	10.7	- 0.9	12.2	11.3	- 0.9
Rush	22.1	29.2	7.1	23.4	30.9	7.5
Shelby	21.5	31.5	10.0	22.8	33.4	10.6
Tipton	29.5	34.4	4.9	20.0	23.3	3.3
Total	20.7	25.6	4.9	327.7	405.0	77.3
East Central District						
Blackford	27.1	26.7	- 0.4	11.7	11.6	- 0.2
Delaware	23.2	32.0	8.8	23.9	33.0	9.1
Fayette	13.0	22.1	9.1	7.2	12.3	5.1
Henry	20.4	23.4	3.0	21.1	24.3	3.1
Jay	26.9	33.3	6.4	26.9	33.3	6.4
Randolph	28.1	32.8	4.7	33.3	38.8	5.5
Union	13.7	14.3	0.6	6.0	6.2	0.3
Wayne	13.5	9.5	- 4.0	14.2	10.0	- 4.2
Total	21.5	25.2	3.7	144.3	169.5	25.2
State	20.1	21.9	1.8	883.5	964.2	80.7

SRS while soybean estimates were different. In the East Central District, both corn and soybean estimates differed significantly from SRS estimates at the 25% level.

In conclusion, compared to SRS, the Landsat estimates of corn area and proportion were consistently overestimated. This is attributed in part to the spectral similarity of corn to other cover types, particularly trees, as well as to factors mentioned earlier such as boundary pixels. Because the corn estimates, although biased, were correlated with the SRS estimates, a regression technique such as described by Wigton [26] might be effectively used if sufficient "ground truth" data were available to determine the magnitude of the bias. On the other hand, the large variation present in soybean estimates would make it infeasible to attempt such a correction. When aggregated, however, the soybean estimates were reasonably close to the SRS estimates.

One further factor, perhaps accounting for some of the differences in the Landsat and SRS estimates, is that the SRS county and district estimates used for comparison are preliminary and may be revised before the final estimates are published in 1977. This possibility was identified when 1974 estimates were examined for use in regression equations to predict crop areas in counties for which Landsat data were not analyzed.

In November 1976, revised 1974 county estimates of corn and soybean acreages were published by SRS. At first glance, these estimates seemed to be different from the preliminary estimates. For prediction of crop acreages where historical data was used (either as an estimate or in a regression) the preliminary figures were used to simulate real-time estimation. However, in a test on a few counties, a regression equation using the revised estimates appeared to give better prediction for 1975.

The Landsat estimates for corn and soybeans did differ from the available SRS estimates which were preliminary. Looking at the changes in the 1974 estimates, it seems possible that the SRS revised estimates may be enough different from the estimates used for comparison that the Landsat estimates may not differ (at least not so much) when compared to the revised figures. It is unfortunate, however, that the revised 1975 estimates will not be available until late in 1977.

To evaluate the difference between the preliminary and revised estimates on a county basis, the relative difference of the preliminary estimate from the revised estimate was calculated. These are presented for each crop and each county in Table 23. Relative differences were as great as 33.3%. This extreme figure occurred in a county with a very small corn and soybean production, but other large relative differences of 10 to 20% occurred where these crops were more important. The differences in hectares of the preliminary from the revised estimates are also given in Table 23. Some estimates have changed by as much as 4000 hectares.

6.3.3 Precision of Estimates

The variance of the corn and soybean estimates can be calculated from the binomial assumptions. If $\hat{\hat{p}}_c$ represents the bias-corrected estimate of proportion corn in a county and $\hat{\hat{p}}_s$ represents the bias-corrected estimate of proportion soybeans in a county, then

$$v\,(\hat{\hat{p}}_c) = \frac{\hat{\hat{p}}_c\left(1-\hat{\hat{p}}_c\right)}{n-1}\,(1-f) \quad \text{and}$$

$$v\,(\hat{\hat{p}}_s) = \frac{\hat{\hat{p}}_s\left(1-\hat{\hat{p}}_s\right)}{n-1}\,(1-f),$$

where n is the number of pixels classified in the county and $f=\frac{n}{N}$ where N is the total number of pixels in the county.

The SRS sampling error is not known, but the sampling error of Landsat estimates is very small in comparison as it is very small absolutely. Sample standard deviations and coefficients of variation for Landsat estimates are presented in Tables 24 and 25. The standard deviations for the crop reporting districts and for the state were calculated considering the sample as stratified with each county considered a stratum. As in Kansas, the sampling error of the state, district, and county crop area estimates is very small.

Table 23. Differences of USDA/SRS preliminary 1974 estimates from revised estimates.

County	Relative Difference (%)		Difference in Hectares	
	Corn	Soybeans	Corn	Soybeans
Northwest District				
Benton	-4.7	6.0	-2145.7	2267.2
Jasper	-5.0	4.4	-3238.9	1457.5
Lake	-4.2	6.0	-1133.6	931.2
LaPorte	-0.1	-3.8	-40.5	-890.7
Newton	-5.1	-3.5	-2388.7	-850.2
Porter	-1.0	-3.1	-283.4	-485.8
Pulaski	1.0	4.7	404.9	1417.0
Starke	0.4	9.8	121.5	1295.5
White	-2.6	4.0	-1376.5	1578.9
North Central District				
Carroll	-0.9	2.5	-404.9	566.8
Cass	-2.8	6.4	-1052.6	1417.0
Elkhart	5.8	-3.2	1619.4	-445.3
Fulton	-1.0	5.1	-283.4	931.2
Kosciusko	-2.9	-4.0	-1174.1	-850.2
Marshall	3.8	-5.4	1295.5	-1012.1
Miami	3.2	-6.2	1012.1	-1214.6
St. Joseph	2.7	-6.9	769.2	-1012.1
Wabash	-0.9	-7.6	-283.4	-1700.4
Northeast District				
Adams	2.4	-8.1	566.8	-2267.2
Allen	-3.2	-2.3	-1012.1	-890.7
DeKalb	6.4	13.3	1093.1	2510.1
Huntington	-1.0	5.0	-242.9	1417.0
LaGrange	-1.0	-7.6	-202.4	-485.8
Noble	-0.9	-3.2	-242.9	-404.9
Steuben	6.0	13.6	1012.1	850.2
Wells	2.1	0.7	566.8	242.9
Whitley	-0.9	7.3	-202.4	1336.0

Table 23. (continued)

County	Relative Difference (%) Corn	Relative Difference (%) Soybeans	Difference in Hectares Corn	Difference in Hectares Soybeans
West Central District				
Clay	-9.2	-15.4	-1740.9	-2955.5
Fountain	4.5	-1.9	1336.0	-485.8
Montgomery	-1.0	-7.7	-485.8	-2550.6
Owen	17.1	6.9	1295.5	445.3
Parke	4.4	5.4	1012.1	931.2
Putnam	-6.8	0.6	-1619.4	121.5
Tippecanoe	-1.0	-4.9	-404.9	-1538.5
Vermillion	24.2	11.6	3279.4	1295.5
Vigo	6.2	0.7	1052.6	121.5
Warren	6.4	0.6	1781.4	161.9
Central District				
Bartholomew	1.8	-1.5	445.3	-242.9
Boone	10.3	-4.0	3684.2	-1133.6
Clinton	-0.9	-0.6	-404.9	-202.4
Decatur	2.5	0.7	890.7	121.5
Grant	0.6	-6.7	161.9	-1943.3
Hamilton	-1.0	-8.2	-283.4	-2064.8
Hancock	-0.9	-0.7	-242.9	-161.9
Hendricks	2.7	-3.3	647.8	-769.2
Howard	-7.1	10.1	-1862.3	2186.2
Johnson	5.9	-0.8	1376.5	-121.5
Madison	-4.6	-13.4	-1619.4	-4048.6
Marion	2.4	5.0	283.4	485.8
Morgan	-0.9	9.7	-161.9	1295.5
Rush	1.1	0.7	445.3	161.9
Shelby	-4.8	0.7	-1902.8	161.9
Tipton	5.3	8.0	1498.0	1781.4
East Central District				
Blackford	3.3	0.6	323.9	81.0
Delaware	-0.9	-3.0	-242.9	-769.2
Fayette	-0.9	0.5	-121.5	40.5
Henry	-8.4	-2.7	-2469.6	-607.3
Jay	14.0	2.1	2388.7	607.3
Randolph	1.8	2.9	526.3	1052.6
Union	-0.9	12.4	-121.5	850.2
Wayne	2.5	10.4	566.8	1740.9

Table 23. (continued)

County	Relative Difference (%) Corn	Relative Difference (%) Soybeans	Difference in Hectares Corn	Difference in Hectares Soybeans
Southwest District				
Daviess	3.1	-2.0	931.2	-283.4
Dubois	2.8	0.7	607.3	40.5
Gibson	-1.0	6.2	-404.9	1376.5
Greene	-2.2	-6.5	-404.9	-688.3
Knox	7.9	-1.3	3967.6	-283.4
Martin	-1.1	22.2	-81.0	404.9
Pike	-0.8	9.9	-121.5	890.7
Posey	4.1	4.6	1295.5	971.7
Spencer	-10.6	3.0	-1578.9	526.3
Sullivan	2.7	7.3	607.3	1336.0
Vanderburgh	8.2	-1.7	1093.1	-202.4
Warrick	-3.8	-13.9	-526.3	-1700.4
South Central District				
Brown	0.0	-33.3	0.0	-161.9
Crawford	0.0	8.3	0.0	81.0
Floyd	0.0	30.0	0.0	242.9
Harrison	-16.9	1.0	-1457.5	40.5
Jackson	4.0	12.2	971.7	1700.4
Lawrence	-0.9	24.1	-81.0	850.2
Monroe	-1.1	10.6	-40.5	202.4
Orange	-12.6	1.2	-1174.1	40.5
Perry	-6.6	1.4	-242.9	40.5
Washington	-23.6	0.7	-4048.6	40.5
Southeast District				
Clark	-3.3	0.6	-242.9	40.5
Dearborn	-18.2	-15.7	-890.7	-445.3
Franklin	-7.7	5.9	-1295.5	445.3
Jefferson	-2.9	-11.4	-202.4	-890.7
Jennings	11.5	8.4	1498.0	890.7
Ohio	-1.8	-17.6	-40.5	-121.5
Ripley	-0.9	12.0	-121.5	1700.4
Scott	-0.8	25.0	-40.5	1255.1
Switzerland	-1.4	0.0	-40.5	0.0

Table 24. Estimates of the standard deviations and coefficients of variation of Landsat estimates of corn in Indiana.

	AREA ESTIMATE		PROPORTION ESTIMATE		
	HECTARES	STANDARD DEVIATION	(%)	STANDARD DEVIATION	COEFFICIENT OF VARIATION
	(000 HA)	(HA)		(%)	(%)
NORTHWEST DISTRICT					
BENTON	53.6	195.97	50.6	0.1849	0.37
JASPER	92.0	499.30	63.3	0.3435	0.54
LAKE	62.7	477.08	47.1	0.3582	0.76
LAPORTE	64.7	510.06	41.1	0.3238	0.79
NEWTON	63.0	467.53	59.2	0.4390	0.74
PORTER	53.1	428.55	48.2	0.3892	0.81
PULASKI	54.1	435.87	48.2	0.3885	0.81
STARKE	38.1	352.25	47.3	0.4371	0.92
WHITE	63.4	208.11	49.2	0.1616	0.33
TOTAL	544.7	1239.02	50.4	0.1147	0.23
WEST CENTRAL DISTRICT					
CLAY	18.0	233.84	19.1	0.2479	1.30
FOUNTAIN	42.2	423.08	41.0	0.4113	1.00
MONTGOMERY	62.2	471.14	47.4	0.3588	0.76
OWEN	19.2	379.55	19.2	0.3805	1.98
PARKE	44.4	592.32	38.0	0.5069	1.33
PUTNAM	36.2	451.09	28.6	0.3567	1.25
TIPPECANOE	53.0	200.56	40.8	0.1545	0.38
VERMILLION	33.5	342.09	49.2	0.5020	1.02
VIGO	21.7	342.62	20.2	0.3186	1.58
WARREN	35.9	196.02	37.6	0.2056	0.55
TOTAL	366.3	1211.80	34.2	0.1130	0.33
CENTRAL DISTRICT					
BARTHOLOMEW	3.4	153.59	3.3	0.1474	4.47
BOONE	5.6	191.23	5.1	0.1728	3.39
CLINTON	2.4	127.60	2.3	0.1210	5.26
DECATUR	37.3	397.20	38.9	0.4147	1.07
GRANT	31.0	177.28	28.4	0.1625	0.57
HAMILTON	38.0	405.14	36.6	0.3899	1.07
HANCOCK	30.6	154.32	38.7	0.1953	0.50
HENDRICKS	48.2	432.73	44.6	0.4005	0.90
HOWARD	39.5	361.32	52.0	0.4759	0.92
JOHNSON	32.6	365.05	39.9	0.4473	1.12
MADISON	46.7	191.20	39.8	0.1629	0.41
MARION	15.1	424.45	14.5	0.4075	2.81
MORGAN	15.3	298.40	14.5	0.2837	1.96
RUSH	38.8	400.08	36.6	0.3775	1.03
SHELBY	54.0	421.18	51.0	0.3974	0.78
TIPTON	33.7	341.94	49.9	0.5056	1.01
TOTAL	472.2	1289.24	29.9	0.0816	0.27
EAST CENTRAL DISTRICT					
BLACKFORD	15.2	260.39	35.2	0.6018	1.71
DELAWARE	43.9	720.23	42.6	0.6984	1.64
FAYETTE	13.3	401.80	23.8	0.7213	3.03
HENRY	23.8	354.60	23.0	0.3421	1.49
JAY	30.9	174.15	30.9	0.1741	0.56
RANDOLPH	49.0	202.96	41.4	0.1714	0.41
UNION	12.4	191.81	28.4	0.4406	1.55
WAYNE	23.0	160.47	21.9	0.1529	0.70
TOTAL	211.5	1003.60	31.4	0.1492	0.48
STATE TOTAL	1594.7	2383.23	36.2	0.0541	0.15

Table 25. Estimates of the standard deviations and coefficients of variation of Landsat estimates of soybeans in Indiana.

	AREA ESTIMATE		PROPORTION ESTIMATE		
	HECTARES	STANDARD DEVIATION	(%)	STANDARD DEVIATION	COEFFICIENT OF VARIATION
	(000 HA)	(HA)		(%)	(%)
NORTHWEST DISTRICT					
BENTON	20.3	154.39	19.2	0.1457	0.76
JASPER	22.4	373.92	15.4	0.2572	1.67
LAKE	22.1	355.62	16.6	0.2670	1.61
LAPORTE	32.9	421.51	20.9	0.2676	1.28
NEWTON	12.4	304.63	11.6	0.2861	2.47
PORTER	21.4	339.14	19.4	0.3080	1.59
PULASKI	32.6	396.22	29.1	0.3532	1.21
STARKE	18.5	296.46	22.9	0.3679	1.61
WHITE	26.4	168.05	20.5	0.1305	0.64
TOTAL	209.0	974.36	19.3	0.0902	0.47
WEST CENTRAL DISTRICT					
CLAY	26.0	265.92	27.6	0.2820	1.02
FOUNTAIN	11.6	272.34	11.3	0.2647	2.34
MONTGOMERY	24.4	367.15	18.6	0.2796	1.50
OWEN	15.6	349.66	15.6	0.3505	2.25
PARKE	9.3	331.06	8.0	0.2833	3.54
PUTNAM	21.1	372.32	16.7	0.2944	1.76
TIPPECANOE	23.4	156.78	18.0	0.1208	0.67
VERMILLION	7.5	214.10	11.0	0.3142	2.86
VIGO	29.6	381.05	27.5	0.3544	1.29
WARREN	12.2	135.20	12.8	0.1418	1.11
TOTAL	180.7	940.49	16.9	0.0877	0.52
CENTRAL DISTRICT					
BARTHOLOMEW	15.7	307.84	15.1	0.2955	1.96
BOONE	38.6	414.32	34.9	0.3745	1.07
CLINTON	37.2	406.79	35.3	0.3857	1.09
DECATUR	15.6	300.93	16.3	0.3142	1.93
GRANT	21.1	155.15	19.3	0.1422	0.74
HAMILTON	29.3	378.45	28.2	0.3642	1.29
HANCOCK	21.8	141.64	27.6	0.1792	0.65
HENDRICKS	30.1	390.45	27.9	0.3614	1.30
HOWARD	22.0	328.17	29.0	0.4323	1.49
JOHNSON	34.9	368.85	42.8	0.4519	1.06
MADISON	28.1	166.59	23.9	0.1419	0.59
MARION	11.7	380.17	11.2	0.3650	3.26
MORGAN	11.3	261.96	10.7	0.2490	2.33
RUSH	30.9	377.63	29.2	0.3563	1.22
SHELBY	33.4	391.37	31.5	0.3693	1.17
TIPTON	23.3	324.87	34.4	0.4804	1.40
TOTAL	405.0	1320.84	25.6	0.0836	0.33
EAST CENTRAL DISTRICT					
BLACKFORD	11.6	241.19	26.7	0.5574	2.09
DELAWARE	33.0	679.42	32.0	0.6588	2.06
FAYETTE	12.3	391.48	22.1	0.7027	3.18
HENRY	24.3	356.74	23.4	0.3442	1.47
JAY	33.3	177.62	33.3	0.1776	0.53
RANDOLPH	38.8	193.46	32.8	0.1634	0.50
UNION	6.2	148.90	14.3	0.3421	2.39
WAYNE	10.0	113.77	9.5	0.1084	1.14
TOTAL	169.5	951.14	25.2	0.1414	0.56
STATE TOTAL	964.2	2118.91	21.9	0.0481	0.22

6.4 Regression Estimation for Corn and Soybeans in Areas Without Landsat Coverage

Landsat data was not analyzed due primarily to cloudiness for five districts in Indiana: North Central, Northeast, Southwest, South Central, and Southeast. Since estimates of the area and proportion of corn and soybeans in these counties were required, a prediction equation was developed for each crop using the 43 counties which had been classified with Landsat data. The Landsat estimates were written as a function of historical crop production in the two previous years, and acres in the county. These equations were then used to predict area and proportion estimates for corn and soybeans in the counties which did not have Landsat coverage.

To estimate the area of corn, the counties classified in Indiana were divided into three groups according to the USDA/SRS 1974 preliminary estimates of acreage of corn (Table 26). The rationale for dividing the counties into groups was to make the variances more homogeneous within groups. A prediction equation was formulated for each of the groups using the variables: acres in the county, the 1973 SRS revised estimate and the 1974 SRS preliminary estimates of acres of corn harvested in the county. The counties in which the area of corn was to be predicted fell into one of these three groups according to the same criterion; however, if the number of acres in the county or the 1973 or 1974 corn acreage estimate fell outside the

Table 26. Groupings used for regression estimation and the number of counties per group.

Group	Counties with Landsat data	Counties to be predicted	USDA/SRS 1974 preliminary acreage estimates
		For Corn Estimation	
1	10	8	<50,000 acres
2	21	13	50-90,000 acres
3	12	3	>90,000 acres
		For Soybean Estimation	
1	12	12	<40,000 acres
2	14	14	40-60,000 acres
3	17	2	>60,000 acres

appropriate range, historical estimation was used. For 26 counties, historical estimates were used.

The prediction equations found are given as follows: for the first group,

$$\hat{y} = 3.98 + 0.01\ x_1 - 0.46\ x_2 + 0.81\ x_3 \quad (R^2 = 0.31);$$

for the second group,

$$\hat{y} = -\ 19.33 + 0.10\ x_1 + 1.22\ x_2 - 0.67\ x_3 \quad (R^2 = 0.30);$$

for the third group,

$$\hat{y} = -\ 69.36 + 0.17\ x_1 - 1.80\ x_2 + 2.33\ x_3 \quad (R^2 = 0.49)$$

where x_1 is the number of thousands of acres in the county, x_2 is the acreage of corn grown in a county in 1973 in thousands, and x_3 is the acreage of corn grown in a county in 1974 in thousands. The "pseudo" Landsat estimate, $\hat{y}$, is given in thousands of hectares.

For soybean estimation, the counties were again divided into three groups, but this time the groupings were based upon the USDA/SRS 1974 preliminary soybean estimates (Table 26). For 21 counties, historical estimation was used. The prediction equations found are given as follows: for the first group,

$$\hat{y} = -\ 2.08 + 0.02\ x_1 + 0.25\ x_2 + 0.17\ x_3 \quad (R^2 = 0.32);$$

for the second group,

$$\hat{y} = -6.71 + 0.04\,x_1 + 0.33\,x_2 \quad (R^2 = 0.20)$$

(the variable x_3 did not add sufficient information to enter the regression);

and for the third group,

$$\hat{y} = 29.87 - 0.03\,x_1 - 0.19\,x_2 + 0.27\,x_3 \quad (R^2 = 0.02);$$

where x_1 is the number of thousands of acres in the county, x_2 is the acreage of soybeans grown in a given county in 1973 in thousands, and x_3 is the acreage of soybeans grown in a county in 1974 in thousands. The "pseudo" Landsat estimate, $\hat{y}$, is given in thousands of hectares. Estimates were then made using these six equations and historical data (Tables 27 and 28).

The estimates made by the prediction equations were generally not of as high an accuracy as the SRS estimates. Estimates of corn area and proportion were not significantly different from SRS estimates at the 25% level in the Northeast and Southeast Districts. In all other districts, however, and for soybean area and proportion estimates in all districts, the regression estimates were significantly different from those obtained by SRS.

Table 27. Regression estimates of area and proportion of corn in counties for which usable Landsat data was not available.

County	*	Hectares (000) SRS	Reg.	Diff.	Proportion (%) SRS	Reg.	Diff.
North Central District							
Carroll	H	44.2	43.4	- 0.8	45.6	44.8	- 0.8
Cass	H	38.7	37.0	- 1.7	36.0	34.4	- 1.6
Elkhart	2	29.8	42.2	12.4	24.6	34.8	10.2
Fulton	2	31.5	36.6	5.1	33.1	38.5	5.4
Koscuisko	3	43.7	37.7	- 6.0	32.3	27.9	- 4.4
Marshall	2	35.5	44.1	8.6	30.9	38.3	7.4
Miami	2	33.2	36.8	3.6	33.7	37.4	3.7
St. Joseph	2	28.9	37.5	8.6	23.9	31.0	7.1
Wabash	2	33.4	43.7	10.3	30.6	40.1	9.5
Total		318.9	359.0	40.1	31.9	35.9	4.0
Northeast District							
Adams	2	23.0	23.4	0.4	25.7	26.2	0.5
Allen	H	34.6	30.6	- 4.0	19.9	17.6	- 2.3
DeKalb	1	18.6	22.6	4.0	19.7	23.9	4.2
Huntington	2	23.5	28.4	4.9	23.3	28.1	4.8
Lagrange	H	25.5	20.8	- 4.7	26.0	21.2	- 4.8
Noble	2	27.1	30.8	3.7	25.5	29.0	3.5
Steuben	1	17.5	23.1	5.6	21.8	28.8	7.0
Wells	2	25.9	27.5	1.6	27.2	28.8	1.6
Whitley	H	22.6	21.3	- 1.3	26.0	24.5	- 1.5
Total		218.3	228.5	10.2	23.6	24.7	1.1

Table 27. (continued)

County	*	Hectares (000) SRS	Reg.	Diff.	Proportion (%) SRS	Reg.	Diff.
Southwest District							
Daviess	2	30.7	39.4	8.7	27.5	35.3	7.8
Dubois	H	23.2	22.3	- 0.9	20.7	19.9	- 0.8
Gibson	3	43.1	42.0	- 1.1	33.3	32.5	- 0.8
Greene	H	21.2	18.3	- 2.9	14.9	12.9	- 2.0
Knox	3	52.0	86.7	34.7	38.8	64.7	25.9
Martin	H	8.7	7.5	- 1.2	9.7	8.4	- 1.3
Pike	1	15.1	19.5	4.4	17.4	22.5	5.1
Posey	2	33.2	38.5	5.3	31.0	35.9	4.9
Spencer	1	18.8	17.4	- 1.4	18.3	17.0	- 1.3
Sullivan	2	23.9	39.2	15.3	20.2	33.1	12.9
Vanderburgh	1	13.8	20.2	6.4	22.1	32.4	10.3
Warrick	1	14.9	19.1	4.2	14.7	18.9	4.2
Total		298.6	370.1	71.5	23.0	28.5	5.5
South Central District							
Brown	H	1.2	1.2	0.0	1.4	1.4	0.0
Crawford	H	2.1	1.9	- 0.2	2.6	2.4	- 0.2
Floyd	H	1.4	1.3	- 0.1	3.6	3.4	- 0.2
Harrison	H	8.3	7.2	- 1.1	6.7	5.8	- 0.9
Jackson	H	27.0	25.3	- 1.7	20.0	18.8	- 1.2
Lawrence	H	9.7	9.2	- 0.5	8.2	7.7	- 0.5
Monroe	H	3.7	3.6	- 0.1	3.7	3.6	- 0.1
Orange	H	10.1	8.2	- 1.9	9.6	7.8	- 1.8
Perry	H	4.4	3.4	- 1.0	4.4	3.4	- 1.0
Washington	H	18.1	13.1	- 5.0	13.5	9.8	- 3.7
Total		86.0	74.4	-11.6	8.4	7.3	- 1.1

Table 27. (continued)

County	*	Hectares (000) SRS	Reg.	Diff.	Proportion (%) SRS	Reg.	Diff.
Southeast District							
Clark	H	7.4	7.1	- 0.3	7.4	7.1	- 0.3
Dearborn	H	5.2	4.0	- 1.2	6.6	5.0	- 1.6
Franklin	1	16.8	20.9	4.1	16.5	20.5	4.0
Jefferson	H	7.7	6.9	- 0.2	8.1	7.3	- 0.8
Jennings	1	12.5	21.6	9.1	12.8	22.1	9.3
Ohio	H	2.0	2.2	0.2	8.9	9.8	0.9
Ripley	H	12.8	12.9	0.1	11.2	11.3	0.1
Scott	H	4.9	4.7	- 0.2	9.8	9.4	- 0.4
Switzerland	H	3.1	2.8	- 0.3	5.4	4.9	- 0.5
Total		72.4	83.1	10.7	10.1	11.6	1.5

*Method of Estimation: H-historical; 1, 2, and 3 refer to the groups defined in Table 26.

Table 28. Regression estimates of area and proportion of soybeans in counties for which usable Landsat data was not available.

County	*	Hectares (000) SRS	Reg.	Diff.	Proportion (%) SRS	Reg.	Diff.
North Central District							
Carroll	2	21.7	24.8	3.1	22.4	25.6	3.2
Cass	2	20.5	23.5	3.0	19.1	21.9	2.8
Elkhart	1	14.0	21.0	7.0	11.5	17.3	5.8
Fulton	2	16.9	20.3	3.4	17.8	21.3	3.5
Koscuisko	2	21.1	24.4	3.3	15.6	18.0	2.4
Marshall	2	17.3	21.0	3.7	15.0	18.3	3.3
Miami	2	18.3	20.7	2.4	18.6	21.0	2.4
St. Joseph	1	14.3	20.5	6.2	11.8	16.9	5.1
Wabash	2	21.8	23.0	1.2	20.0	21.1	1.1
Total		165.9	199.2	33.3	16.6	19.9	3.3
Northeast District							
Adams	H	26.7	25.8	- 0.9	29.9	28.9	- 1.0
Allen	H	34.8	37.3	2.5	20.0	21.5	1.5
DeKalb	2	16.8	20.5	3.7	17.8	21.7	3.9
Huntington	3	27.8	28.9	1.1	27.5	28.6	1.1
Lagrange	H	5.5	5.9	0.4	5.6	6.0	0.4
Noble	1	12.0	17.6	5.6	11.3	16.6	5.3
Steuben	H	5.3	7.1	1.8	6.6	8.8	2.2
Wells	3	31.9	29.7	- 2.2	33.5	31.2	- 2.3
Whitley	2	17.2	18.1	0.9	19.8	20.8	1.0
Total		178.0	190.9	12.9	19.2	20.6	1.4

Table 28. (continued)

County	*	Hectares (000) SRS	Reg.	Diff.	Proportion (%) SRS	Reg.	Diff.
Southwest District							
Daviess	1	12.5	19.1	6.6	11.2	17.1	5.9
Dubois	H	5.3	5.8	0.5	4.7	5.2	0.5
Gibson	2	20.0	25.9	5.9	15.5	20.0	4.5
Greene	1	10.0	17.0	7.0	7.0	12.0	5.0
Knox	2	20.0	25.3	5.3	14.9	18.9	4.0
Martin	H	1.7	2.2	0.5	1.9	2.5	0.6
Pike	1	8.2	13.0	4.8	9.4	15.0	5.6
Posey	2	19.1	23.2	4.1	17.8	21.6	3.8
Spencer	2	17.0	20.1	3.1	16.6	19.6	3.0
Sullivan	2	16.4	22.3	5.9	13.8	18.8	5.0
Vanderburgh	1	10.8	14.7	3.9	17.3	23.5	6.2
Warrick	1	11.7	15.6	3.9	11.6	15.4	3.8
Total		152.7	204.2	51.5	11.8	15.7	3.9
South Central District							
Brown	H	0.4	0.3	- 0.1	0.5	0.4	- 0.1
Crawford	H	0.9	1.1	0.2	1.1	1.4	0.3
Floyd	H	0.8	1.1	0.3	2.1	2.9	0.8
Harrison	H	4.0	4.2	0.2	3.2	3.4	0.2
Jackson	1	13.4	23.2	9.8	9.9	17.2	7.3
Lawrence	H	3.4	4.4	1.0	2.9	3.7	0.8
Monroe	H	1.8	2.1	0.3	1.8	2.1	0.3
Orange	H	3.0	3.3	0.3	2.9	3.1	0.2
Perry	H	2.7	3.0	0.3	2.7	3.0	0.3
Washington	H	5.4	5.7	0.3	4.0	4.3	0.3
Total		35.8	48.4	12.6	3.5	4.8	1.3

Table 28. (continued)

County	*	Hectares (000) SRS	Reg.	Diff.	Proportion (%) SRS	Reg.	Diff.
Southeast District							
Clark	H	6.0	6.3	0.3	6.0	6.3	0.3
Dearborn	H	2.6	2.4	- 0.2	3.3	3.0	- 0.3
Franklin	1	6.8	11.8	5.0	6.7	11.6	4.9
Jefferson	H	7.4	6.9	- 0.5	7.8	7.3	- 0.5
Jennings	1	10.2	16.0	5.8	10.4	16.4	6.0
Ohio	H	0.6	0.6	0.0	2.7	2.7	0.0
Ripley	1	13.5	20.9	7.4	11.8	18.3	6.5
Scott	H	4.7	6.3	1.6	9.4	12.6	3.2
Switzerland	H	2.0	2.1	0.1	3.5	3.7	0.2
Total		53.8	73.3	19.5	7.5	10.2	2.7

*Method of Estimation: H-historical; 1, 2, and 3 refer to the groups defined in Table 26.

7.0 SIGNIFICANT RESULTS AND CONCLUSIONS

The first sections of this report described the rationale and background of this research, defined the objectives and experimental approach, and presented the results. Many different phases of our investigation have produced results which we believe are significant in the development of remote sensing technology, particularly for crop surveys. New techniques for handling and analyzing multispectral scanner data were developed; crops were classified over larger areas than ever before. The results conclusively demonstrated the efficiency and applicability of computer-aided analysis techniques for estimating crop areas. The objectives and approach are briefly reviewed in this section; then the most significant results and conclusions are presented.

The overall objective of the investigation was to develop and test techniques utilizing Landsat MSS data to identify and determine the areal extent and distribution of crops over large geographic areas. The specific objectives were:

- Using Landsat data and computer-implemented pattern recognition, classify the major crops from regions encompassing different climates, soils and crops.

- Estimate crop areas for county and state size regions using identification data obtained from Landsat classifications.

- Evaluate the accuracy, precision and timeliness of crop estimates obtained from Landsat data.

The test areas and crops were Kansas, winter wheat, and Indiana, corn and soybeans. The major steps of the experimental approach used were:

- Use aerial photography as reference data for training the classifier.

- For counties without reference data, extend training statistics from adjacent counties having similar crops and soils.

- Classify and make area estimates from a systematic random sample of pixels distributed over an entire county.

- Adjust estimates for classification bias.

- Aggregate county estimates to district and state levels.

- Perform quantitative statistical evaluation of results using the area estimates made by USDA/SRS as a standard of comparison.

Landsat data acquired during March to June for the counties in seven crop districts of Kansas were classified; estimates of the area of wheat in each of the 80 counties were made and compared to the corresponding estimates made by the USDA/SRS. The correlation of the USDA/SRS county estimates of wheat area to the Landsat estimates was 0.80. The wheat proportion estimates of 49% of the Landsat county estimates were within $\pm$ 5% of the SRS estimates and 81% were within $\pm$ 10%. At the crop reporting district level there was a significant difference in the Landsat and SRS estimates in only one of the seven districts. In that district the differences, although small, were all in one direction. For the state, the SRS estimate was 4,555,000 hectares compared to the Landsat estimate of 4,613,000 hectares, a relative difference of only 1.27%.

The coefficient of variation, a measure of the precision or sampling error, of the Landsat estimates was 0.06% compared to 4% for SRS estimates at the state level. The median coefficient of variation of the Landsat county estimates was 0.60%. At all levels, state, district, and county, the Landsat estimates were extremely precise compared to the corresponding USDA/SRS estimates.

Landsat data acquired during July, August, or September for 43 counties in four districts were classified for the Indiana portion of the study. The corn and soybean classification performances and area estimates were not as accurate as for wheat in Kansas. The correlation coefficients for Landsat and SRS county estimates of the areas of corn and soybeans were 0.67 and 0.56, respectively. The corn estimates were consistently high compared to SRS and the soybean estimates, although not biased as for corn, varied widely from SRS. There were also significant differences in the SRS and Landsat estimates at the district and state levels. As in Kansas, the Indiana Landsat estimates were very precise compared to the SRS estimates.

The generally lower level of performance in Indiana compared to Kansas is attributed to the greater number of crops and spectral classes to discriminate among; smaller, less homogeneous fields; less optimal timing of Landsat data acquisition; and less adequate reference or training data. A major difference between winter wheat identification in Kansas and corn and soybean identification in Indiana is that the crop calendar of winter wheat is different than most other cover types; whereas, corn and soybeans, both summer crops, have crop calendars similar to other cover types present, (i.e. are green at the same time) such as oats, hay, pasture, and trees. In summary, the identification of corn and soybeans in Indiana is a much more difficult problem than winter wheat identification in Kansas. This fact was compounded by the lack of cloud-free Landsat data at critical times and inadequate reference data for optimal training of the classifier.

Results in both Kansas and Indiana could be improved by the following changes which can be recommended based on the results obtained in this investigation. In the area of stratification there are two recommendations: first, apply a more systematic, objective procedure for subdividing the scene into homogeneous areas, and second, use classification units smaller than a county when a county falls into more than one stratum. Two improvements in the area of data acquisition would be beneficial: first, coordinate aerial photography acquisition more closely with the crop calendar and Landsat data acquisition; second, more timely delivery of Landsat data could be used to facilitate scheduling aerial photography missions. Finally, the computer costs for classification could be decreased by reducing the sampling fraction from 25% to either 6.25 or 4% without significantly affecting the accuracy or precision of the estimates.

The overall conclusions of the investigation are:

- Landsat MSS data was adequate to accurately identify wheat in Kansas; corn and soybean estimates for Indiana were less accurate.

- Computer-aided analysis techniques can be effectively used to extract crop identification information from Landsat data.

- Systematic sampling of entire counties made possible by computer classification methods resulted in very precise area estimates at county, district, and state levels.

- Training statistics can be successfully extended from one county to other counties having similar crops and soils if the training areas sampled the total variation of the area to be classified.

The synoptic view of Landsat provides the opportunity to obtain crop production information over very large areas, e.g. states and countries. By using computer processing techniques to classify pixels distributed over entire counties, it is also possible to make accurate and precise estimates for local areas, e.g. counties. These capabilities combining satellite, sensor, and computer make a worldwide, and at the same time, a local crop production information system possible. The procedures and results of this investigation should be of particular interest to U.S. government "user" agencies including the Statistical Reporting Service, the Foreign Agricultural Service, and the Economic Research Service; international organizations such as the United Nations' Food and Agriculture Organization; and private firms such as grain exporting companies.

8.0 RECOMMENDATIONS

The experiences and results of this research with Landsat data have indicated a number of recommendations which should be considered in designing and implementing future satellite sensor/data processing systems. These are as follows:

Frequency of Data Collection: The 18 day collection sequence available with Landsat-2 proved to be inadequate for several phases of this study; although Landsat-1 data was used to fill in several gaps in the data, it was not readily available. An 8 to 10 day cycle would be much more satisfactory for crop surveys in the future. Because of frequent cloud cover problems, such an increase in frequency of coverage would assure a higher probability for collection of adequate quantity and quality of data during critical periods of the vegetative growing season. More frequent coverage than 18 days will also be required for monitoring crop conditions.

Wavelength Bands: Work with aircraft data and more recently with Skylab data has clearly shown the importance of the middle infrared and thermal infrared portions of the spectrum for crop identification. Because the Landsat scanner does not obtain data in these wavelength regions, we believe that the classification accuracies achieved are not as high as would be possible. Addition of at least one wavelength band in the middle infrared portion of the spectrum (1.3-2.6μm) and at least one channel in the 8-13.5μm thermal infrared region in future satellite scanner systems will unquestionably allow significant improvements in many of the results obtained, and in the utility of this type of satellite data. Further, the narrower and more optimally placed visible and near infrared bands of the proposed thematic mapper sensor on Landsat D will be a substantial improvement [21].

Spatial Resolution: The 80 meter IFOV of the current Landsat MSS appears generally adequate for areas having relatively large fields, but it is definitely a limitation in working in areas with field sizes of 10 hectares or less. The 30 meter IFOV of the proposed thematic mapper sensor would be a major improvement in that it would greatly reduce the proportion of "mixed" field boundary pixels and facilitate locating field boundaries.

Time of Day: To maximize the signal/noise ratio and minimize the effect of shadows, Landsat overpasses near solar noon would be optimal. However, because of the normal mid-day build-up of cumulus clouds, it appears that the time of day utilized is nearly ideal, and a change in the time of data collection is not recommended for future systems.

Delays in Receipt of Data: Lengthy delays in receipt of data in either image or tape format precluded the possibility of a rapid analysis of the data and subsequent field checking. It is highly recommended that a system be developed to get an intermediate quality product into the hands of the investigators within 2-4 days after data collection. If cloud cover was minimal and overall data quality appeared promising, the investigator could then request tapes and final image product outputs and more intelligently schedule and utilize resources in collecting "ground truth."

Reference Data for Training: The importance of high quality, accurate reference data for training the classifier should be emphasized. A multistage sampling system combining coordinated ground observations; large scale aerial photography; small scale, high altitude photography; and Landsat data would be ideal and insure the greatest accuracy in the classification of Landsat data. However, in most instances one or two of the stages are sufficient and as additional knowledge and understanding of the multispectral responses of crops is gained, greater dependence can be placed on developing training statistics directly from the Landsat data. This approach is being utilized by LACIE for wheat and should be developed for other crops and regions.

Geometric Correction and Multitemporal Registration: Although neither geometrically corrected or multitemporally registered data were utilized in this investigation because of the current high cost of obtaining such data, both kinds of preprocessing should be made routinely available in order to increase the utility and performance of Landsat data. In this investigation geometrically corrected digital data would have considerably simplified the task of obtaining field and county coordinates. The ability to register multiple data sets is becoming increasingly important in that it allows the temporal dimension of the spectral measurements to be fully utilized, and will also allow satellite data to be effectively related to other maps. Future systems should provide a digital data format that has been geometrically corrected to a standard format base to facilitate data registration.

Data Analysis Techniques: Improvements in data analysis techniques are required to fully achieve the potential information content of multitemporal, spectral measurements acquired from space. The spatial dimension has been little used to date in computer-aided data analysis, although spatial characteristics are known to bear a great amount of information and are regularly used by photo interpreters. Still another aspect of satellite data analysis is the need to develop methods for effectively working over the large geographic areas for which Landsat data is obtained. The diversity of landscape patterns found over many areas of this size indicates that a logical first step in the classification of Landsat data is to stratify or divide the scene into units which are internally similar. Such a stratification will be helpful in constructing sampling frames which minimize the variance among sample units and in determining the boundaries of areas over which training statistics can be satisfactorily extended.

Crop Yield Prediction: Although yield prediction or crop assessment was not an objective or within the scope of this investigation, there were indications as we analyzed the data that some of the observed variations in spectral response were due to factors which are related to yield such as amount of tillering, leaf area, and biomass. These relationships as well as the use of Landsat data to determine the extent and severity of catastrophic events such as drought should be explored in future studies.

In closing, we believe considerable progress toward an operational crop survey system was made as a result of this experiment. The results conclusively demonstrated the efficiency and applicability of computer-aided analysis techniques for estimating crop areas. Many of the techniques used in the investigation could be transferred to an operational system capable of producing accurate and precise crop area estimates for local areas such as counties, as well as for larger areas such as states or countries.

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APPENDIX

Table A1. Summary of Landsat scenes and sources of training statistics used for classifications in Kansas.

County	Source of Training Statistics	Landsat Scene	Date
Northwest District			
Cheyenne	(local)	2165-16450	July 6, 1975
Decatur	Norton	2146-16392	June 17, 1975
Graham	(local)	2146-16395	June 17, 1975
Norton	(local)	2146-16392	June 17, 1975
Rawlins	Cheyenne	2165-16450	July 6, 1975
Sheridan	Trego	2146-16395	June 17, 1975
Sherman	(local)	2165-16453	June 7, 1975
Thomas	Sherman	2165-16453	June 7, 1975
North Central District			
Clay	Ottawa	2144-16282	June 15, 1975
Cloud	(local)	2163-16334	July 4, 1975
Jewell	Smith	2163-16334	July 4, 1975
Mitchell	Osborne	2163-16340	July 4, 1975
Osborne	(local)	2163-16340	July 4, 1975
Ottawa	(local)	2144-16282	June 15, 1975
Phillips	Norton	2146-16392	June 17, 1975
Republic	Cloud	2163-16334	July 4, 1975
Rooks	Graham	2146-16395	June 17, 1975
Smith	(local)	2163-16334	July 4, 1975
Washington	Cloud	2163-16334	July 4, 1975
West Central District			
Gove	Trego	2146-16395	June 17, 1975
Greeley	(local)	2165-16453	July 6, 1975
Lane	Trego	2146-16395	June 17, 1975
Logan	Wallace	2165-16453	July 6, 1975
Ness	(local)	2146-16395	June 17, 1975
Scott	Greeley	2165-16453	July 6, 1975
Trego	(local)	2146-16395	June 17, 1975
Wallace	(local)	2165-16453	July 6, 1975
Wichita	Greeley	2165-16453	July 6, 1975
Central District			
Barton	(local)	2163-16340	July 4, 1975
Dickinson	Saline	2144-16282	June 15, 1975
Ellis	Trego	2146-16395	June 17, 1975

Table A1. (continued)

<u>Central District (cont.)</u>			
Ellsworth	Russell	2163-16340	July 4, 1975
Lincoln	Russell	2163-16340	July 4, 1975
McPherson	(local)	2144-16282	June 15, 1975
Marion	McPherson	2144-16282	June 15, 1975
Rice	Barton	2163-16340	July 4, 1975
Rush	Trego	2146-16395	June 17, 1975
Russell	(local)	2163-16340	July 4, 1975
Saline	(local)	2144-16282	June 15, 1975
<u>Southwest District</u>			
Clark	Ford	5032-16310	May 21, 1975
Finney	(local)	5032-16310	May 21, 1975
Ford	(local)	5032-16310	May 21, 1975
Grant	Hamilton	2147-16460	June 18, 1975
Gray	Haskell	5032-16310	May 21, 1975
Hamilton	(local)	2147-16460	June 18, 1975
Haskell	(local)	5032-16310	May 21, 1975
Hodgeman	(local)	2146-16395	June 17, 1975
Kearney	Hamilton	2147-16460	June 18, 1975
Meade	Ford	5032-16310	May 21, 1975
Morton	Stanton	2147-16460	June 18, 1975
Seward	(local)	5032-16310	May 21, 1975
Stanton	(local)	2147-16460	June 18, 1975
Stevens	Hamilton	2147-16460	June 18, 1975
<u>South Central District</u>			
Barber	(local)	2073-16342	April 5, 1975
Barber	(local)	2109-16341	May 11, 1975
Comanche	Pratt	2073-16342	April 5, 1975
Comanche	Pratt	2109-16341	May 11, 1975
Edwards	Pratt	2073-16342	April 5, 1975
Edwards	Pratt	2109-16341	May 11, 1975
Harper	Sumner	2072-16284	April 4, 1975
Harper	Sumner	2144-16284	June 15, 1975
Harvey	(local)	2072-16284	April 4, 1975
Harvey	(local)	2144-16284	June 15, 1975
Kingman	Pratt	2073-16342	April 5, 1975
Kingman	Pratt	2109-16341	May 11, 1975
Kiowa	Pratt	2073-16342	April 5, 1975
Kiowa	Pratt	2109-16341	May 11, 1975
Pawnee	Stafford	2073-16342	April 5, 1975
Pratt	(local)	2073-16342	April 5, 1975
Pratt	(local)	2109-16341	May 11, 1975
Reno	Stafford	2073-16342	April 5, 1975
Sedgwick	Sumner	2072-16284	April 4, 1975

Table A1. (continued)

South Central District (cont.)			
Sedgwick	Sumner	2144-16284	June 15, 1975
Stafford	(local)	2073-16342	April 5, 1975
Sumner	(local)	2072-16284	April 4, 1975
Sumner	(local)	2144-16284	June 15, 1975
Southeast District			
Allen	(local)	2142-16171	June 13, 1975
Allen	(local)	2107-16225	May 9, 1975
Bourbon	Allen	2142-16171	June 13, 1975
Butler	Harvey	2144-16284	June 15, 1975
Chautauqua	Allen	2107-16225	May 9, 1975
Cherokee	Allen	2142-16171	June 13, 1975
Cowley	Sumner	2144-16284	June 15, 1975
Crawford	Allen	2142-16171	June 13, 1975
Elk	Allen	2107-16225	May 9, 1975
Greenwood	Allen	2107-16225	May 9, 1975
Labette	Allen	2142-16171	June 13, 1975
Montgomery	Allen	2107-16225	May 9, 1975
Neosho	Allen	2142-16171	June 13, 1975
Wilson	Allen	2107-16225	May 9, 1975
Woodson	Allen	2107-16225	May 9, 1975

Table A2. Summary of Landsat scenes and sources of training statistics used for classification in Indiana.

County	Source of Training Statistics	Landsat Scene	Date
Northwest District			
Benton	(local)	2228-15522	Sept. 7, 1975
Jasper	Newton	2228-15515	Sept. 7, 1975
Lake	(local)	2228-15515	Sept. 7, 1975
LaPorte	(local)	2228-15515	Sept. 7, 1975
Newton	(local)	2228-15515	Sept. 7, 1975
Porter	Lake	2228-15515	Sept. 7, 1975
Pulaski	(local)	2228-15515	Sept. 7, 1975
Starke	(local)	2228-15515	Sept. 7, 1975
White	(local)	2228-15522	Sept. 7, 1975
West Central District			
Clay	Vigo	2173-15480	July 14, 1975
Fountain	(local)	2228-15522	Sept. 7, 1975
Montgomery	(local)	2209-15464	Aug. 19, 1975
Owen	(local)	2173-15480	July 14, 1975
Parke	(local)	2228-15522	Sept. 7, 1975
Putnam	Owen	2173-15480	July 14, 1975
Tippecanoe	(local)	2228-15522	Sept. 7, 1975
Vermillion	Parke	2228-15522	Sept. 7, 1975
Vigo	(local)	2173-15480	July 14, 1975
Warren	(local)	2228-15522	Sept. 7, 1975
Central District			
Bartholomew	Decatur	2208-15412	Aug. 18, 1975
Boone	Hamilton	2209-15464	Aug. 19, 1975
Clinton	Tipton	2209-15464	Aug. 19, 1975
Decatur	(local)	2208-15412	Aug. 18, 1975
Grant	(local)	2209-15464	Aug. 19, 1975
Hamilton	(local)	2209-15464	Aug. 19, 1975
Hancock	(local)	2208-15405	Aug. 18, 1975
Hendricks	Hamilton	2209-15464	Aug. 19, 1975
Howard	(local)	2209-15464	Aug. 19, 1975
Johnson	(local)	2208-15412	Aug. 18, 1975
Madison	(local)	2208-15405	Aug. 18, 1975
Marion	Hamilton	2209-15464	Aug. 19, 1975
Morgan	Owen	2173-15480	July 14, 1975
Rush	Shelby	2208-15412	Aug. 18, 1975
Shelby	(local)	2208-15412	Aug. 18, 1975
Tipton	(local)	2209-15464	Aug. 19, 1975

Table A2. (continued)

East Central District

Blackford	Jay	2208-15405	Aug. 18, 1975
Delaware	Randolph	2208-15405	Aug. 18, 1975
Fayette	(local)	2208-15412	Aug. 18, 1975
Henry	Wayne	2208-15405	Aug. 18, 1975
Jay	(local)	2208-15405	Aug. 18, 1975
Randolph	(local)	2208-15405	Aug. 18, 1975
Union	Fayette	2208-15412	Aug. 18, 1975
Wayne	(local)	2208-15405	Aug. 18, 1975